The University of Michigan
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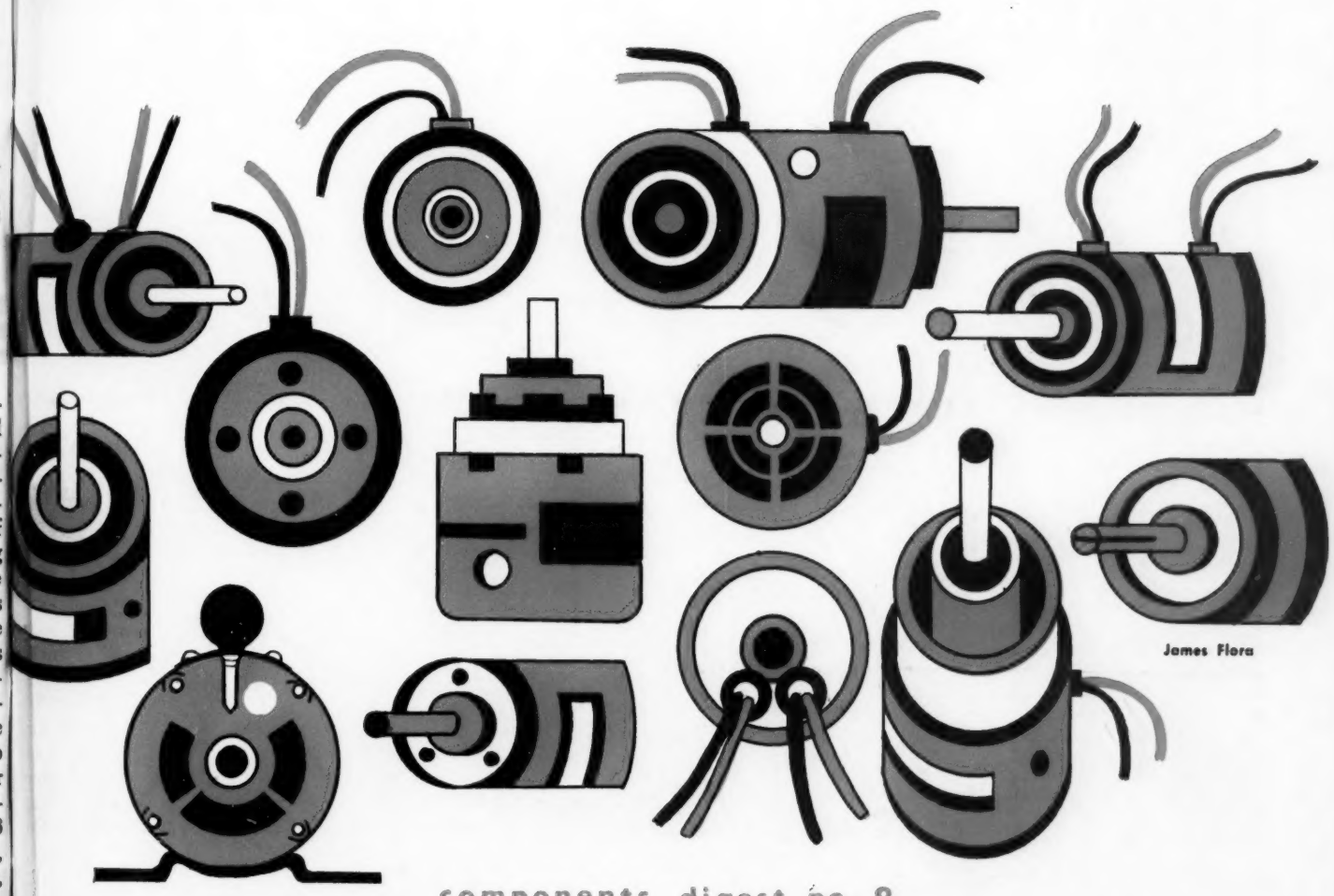
ELECTROMECHANICAL
components & systems DESIGN

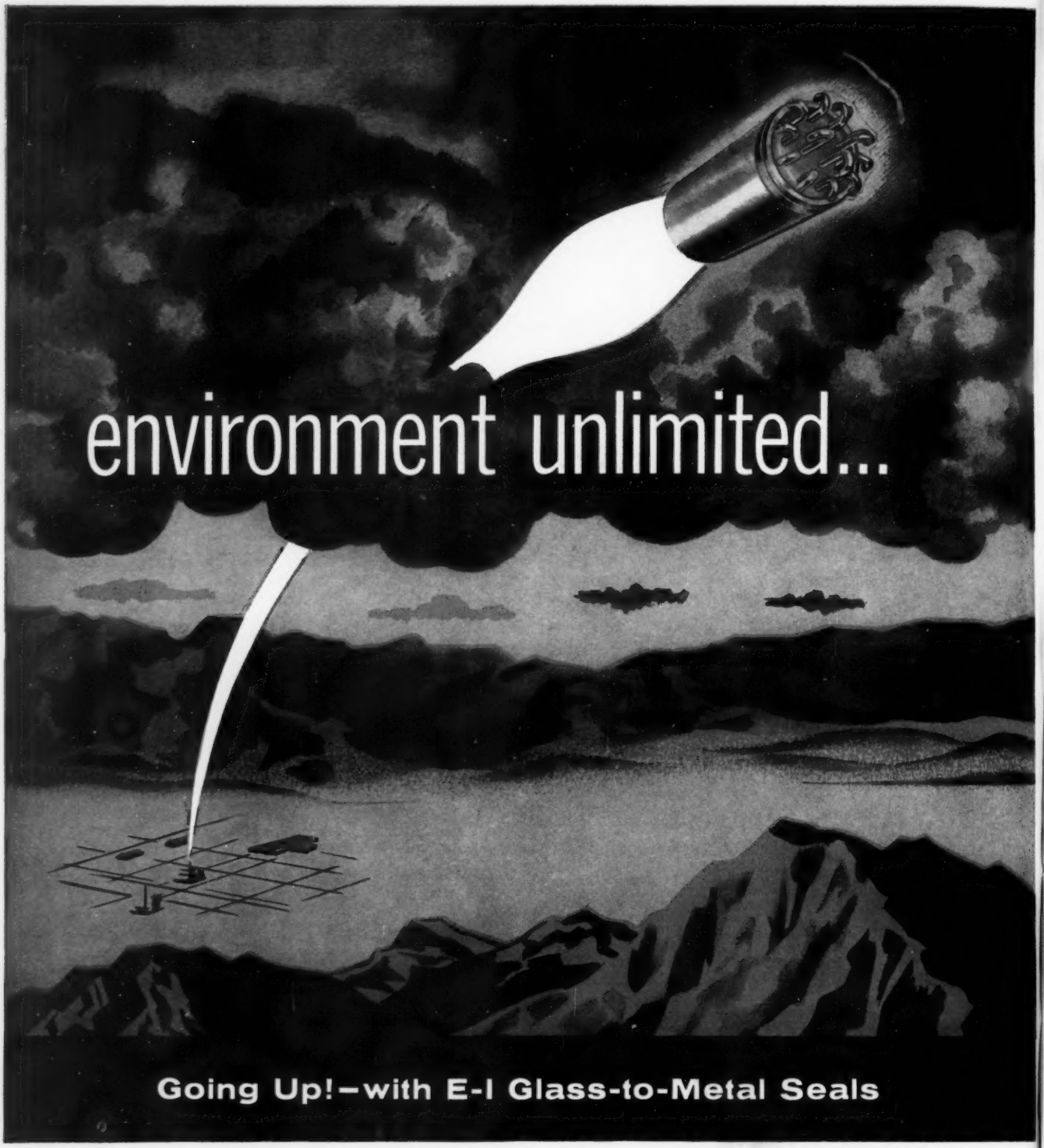
SEPTEMBER 1959



James Flora

components digest no. 9

fractional horsepower induction motors



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CIRCLE 69 ON INQUIRY CARD

The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3, NO. 9

SEPTEMBER 1959

ELECTROMECHANICAL components & systems DESIGN

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Miniature Closures

Threaded End Seals

Circulation for September: over 28,000

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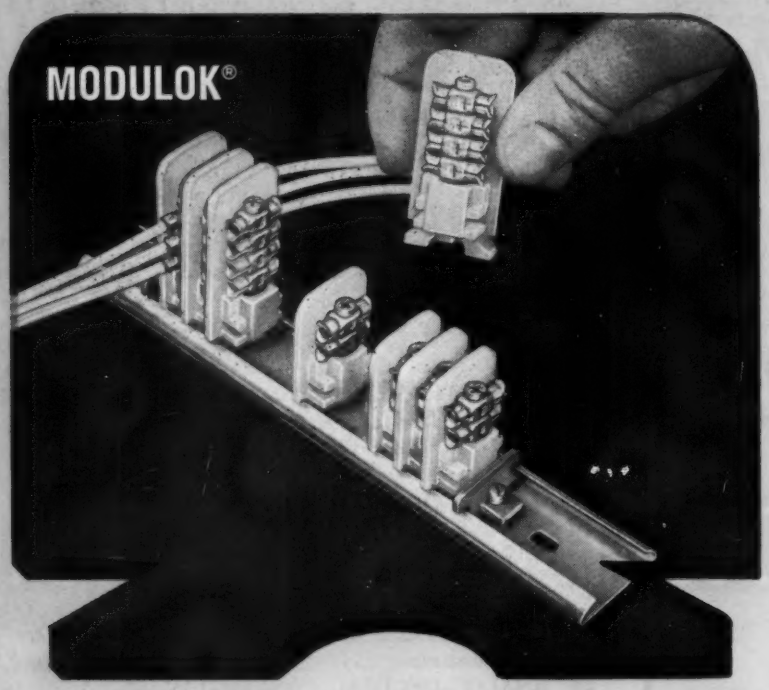

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CIRCLE 1 ON INQUIRY CARD

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Published monthly by Benwill Publishing Corporation. Harold G. Buchbinder, President; Milton Berns, George Palken, Robert B. Brotherston, Vice Presidents, Executive, Editorial and Subscription Office 1357 Washington St., West Newton 65, Mass. Telephone BIgelow 4-9006.
Copyright 1959 by Benwill Publishing Corporation. Accepted as controlled circulation publication at Orange, Conn.

Postmaster: send form 3579 to Benwill Publishing Corporation, 1357 Washington St., West Newton 65, Mass.

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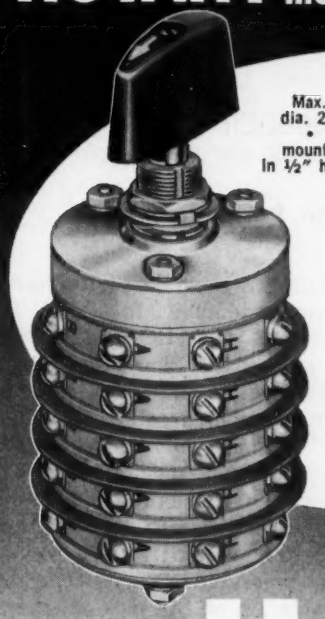
ROTARY multi-pole multi-circuit SWITCHES



TYPE **JL**

TYPE **MA-12**

FOR ELECTRIC CIRCUITS:

TYPE JL rotary switch is a low-power switch with an electrical rating of 5 amperes, 125 volts a-c. A maximum of eight positions — up to ten sections — are controlled by a single knob. This type permits unlimited rotation in both directions but can be limited to any number up to eight positions by two stop screws. It is designed for single-hole panel mounting. Meets MIL-S-21604 and BuShips Drawing Number 9000-S6202-74422. Write for free Bulletin 101-A containing comprehensive data.

FOR ELECTRONIC CIRCUITS:

TYPE MA-12 is a miniature rotary switch with an electrical rating of 3 amperes, 115 volts a-c. A maximum of six contact positions — up to five sections — are controlled by a single knob mounted on a ¼" shaft. Rotation can be unlimited in both directions but can be limited from two to twelve positions by two stop screws. This type rotary switch mounts in ¾" square, single-hole panel mounting. Designed to meet MIL-S-3786.

ESCO has a broad line of other standard rotary switches with electrical ratings up to 200 amperes. Parts of these standard switches may be assembled in a different manner in order to meet unusual or highly specialized circuit control requirements. These special combinations may comply with BuShips Drawings and MIL-Specifications. Write for Bulletin 8-A giving detailed information.

ESCO of WEYMOUTH
ELECTRO SWITCH CORPORATION
167 King Avenue, Weymouth 88, Massachusetts

CIRCLE 2 ON INQUIRY CARD

MAGNETIC SHAFT-POSITION DIGITAL ENCODER

New Pick-off Design Removes Limitation On Resolution

Magnetic shaft-position digital encoders have the important advantages that characterize electromagnetic devices: they are simple, rugged, inexpensive units with practically unlimited life and effectively no temperature limitations. Their only non-ideal characteristic has been resolution. Minimum bit width has been limited by the minimum width of an effective magnetic pick-off core.

Engineers at Machine Tool Automation, Inc., Southport, Conn., applying techniques they say are well known to electromechanical engineers experienced in design of electromagnetic devices, have developed a magnetic encoder with a pick-off core so narrow that it no longer limits resolution. Their present model is a 3-15/16 inch diameter encoder with a resolution of 2^{10}, which is equivalent to a 0.012 inch quantum width on the outermost code disc track. They are working on a design expected to have a quantum width of 0.00075 inch. The limiting factor in this design, they say, will be in the fabrication and aligning of the code disc. Problems in this new design, then, will be similar to those in design of photoelectric devices where exceedingly high resolutions have been achieved.

ENCODER OPERATION

In describing the operation of the magnetic encoder we will assume a general knowledge of how a brush-type encoder works. The code disc patterns consist of concentric tracks each representing a binary digit. The least significant digit track is at the circumference and the most significant at the center. In the brush type encoder, each track is divided into segments which provide either a conducting or nonconducting path to the pick-off brush associated with the track. In the magnetic unit each track is divided into alternate segments of soft magnetic material and holes which provide either a conducting or nonconducting flux path in a magnetic pick-off circuit. Fig. 1 illustrates the design and operation of the magnetic circuit. On the pick-off core are two windings. One winding is excited by an alternating current tending to force flux through the magnetic circuit. The amount of flux that flows depends on the reluctance of the path as determined by whether a solid segment or a "hole" segment of the code disc track is under the pick-off core. The second winding generates an output voltage proportional to the flux flow in the pick-off core. Thus the pick-off reads the binary code on its code disc track at the tip of the pick-off.

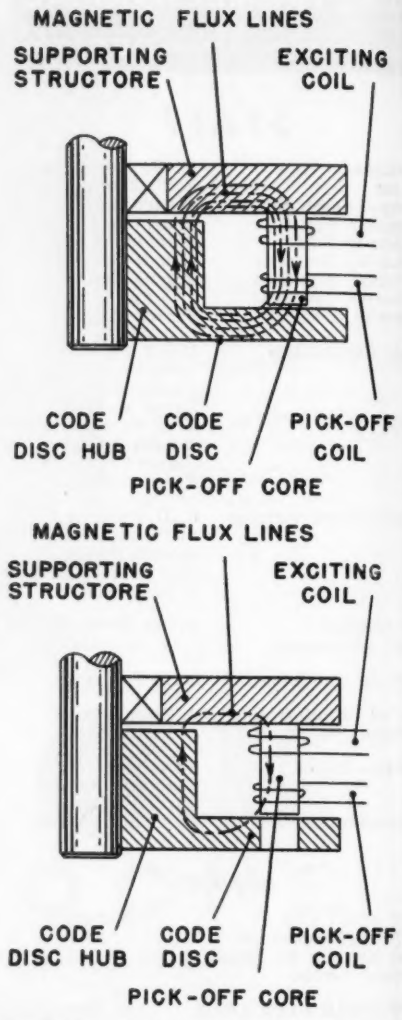
THE DESIGN

The major problem in the magnetic circuit design was obtaining sufficient contrast between the output signal for a "one" and for a "zero". This problem involved design of the pick-off core which, as has been said, was a critical factor in the objective of fine resolution. In the first experimental model, flux leakage in the magnetic circuit when the pick-off core was over a "hole" segment in the code disc track resulted in an output signal indistinguishable from that for a solid segment. This leakage flowed from the sides of the pick-off core to the disc. Although the flux density of the leakage flowing through the high reluctance air path is very small, it nonetheless can be of major significance because of the large leakage areas involved compared to the area of the pick-off tip. Fig. 2 compares performance of the first experimental encoder without leakage control with that of the final production design.

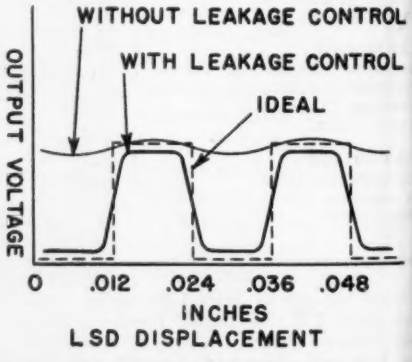
Originally manufacture of the magnetic code discs was a problem because no one in the photo etching business was experienced with them. But now these people are familiar with the process, they can produce discs easily by the hundreds.

An important characteristic of magnetic code discs is that flatness is not critical as it is in brush code discs. As a result magnetic discs are inexpensive to produce.

Ruggedness of the magnetic circuit of the encoder and absence of any brush contacts or electronics or light emitting and sensing components make the unit simple and reliable. Quoted temperature limits for the 2^{10} unit are −65 to +150C but these limits can be extended.



Operation of the encoder magnetic circuit. The upper diagram illustrates the high reluctance of the flux path when a "hole" segment of the code disc track is under the tip of the pick-off core. The lower diagram shows the low reluctance path when a segment of soft magnetic material is under the tip. The problem in the design was to minimize flux leakage in the high reluctance path.



Comparison of magnetic encoder output before and after flux leakage was controlled.

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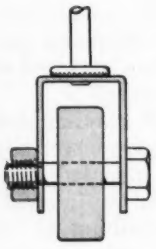
. . . improves fastener reliability and reduces costs!

LOCTITE sealant makes ordinary fasteners into lock fasteners at savings of 40%-70%. Locking action extends over the entire engaged area providing unequalled resistance to vibration . . . ends breakdowns due to loosening of fasteners. A single drop of LOCTITE replaces all sizes of lock nuts, lock washers, lock screws, jam nuts, staking and interference threads.

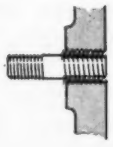
– ELIMINATES LOCK WASHER OR SELF-LOCKING SCREW

Makes ordinary screws into lock screws. Several times the holding power at savings of $20/M.



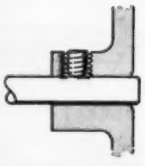
–ELIMINATES SELF-LOCKING NUT OR JAM NUT

Locks non-seated nuts anywhere along the length of thread.



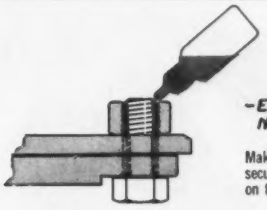
–ELIMINATES INTERFERENCE FIT

Locks studs securely . . . locking action develops after stud is in place . . . allows easy-driving Class 2 threads. End stripped threads, broken studs, damaged castings.



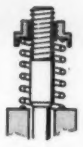
–ELIMINATES DOUBLE SET SCREWS, SELF-LOCKING SET SCREWS, JAM NUTS ON EXTENDED SET SCREWS OR STAKING

LOCTITE-treated set screws cannot vibrate loose . . . end nuisance service calls.



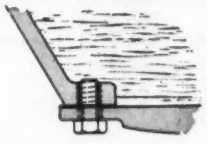
–ELIMINATES SELF-LOCKING NUT OR LOCK WASHER

Makes any nut a lock nut. Saves 40%-70%. Holds securely where lockwashers fail. Does not depend on tightening torque for locking action.



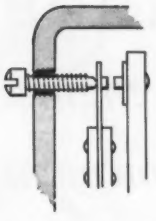
–ELIMINATES SPECIALS OR STAKING

Makes any threaded part self-locking.



– ELIMINATES BLIND HOLE TAPPING, SPECIAL LEAK-PROOF FASTENERS

LOCTITE locks and seals threaded parts against vibration and high-pressure fluids.



– ELIMINATES SELF-LOCKING SCREW OR JAM NUT

Get the right setting the first try . . . no backlash. LOCTITE provides the proper amount of drag to hold adjustment securely. Permits repeated adjustments.

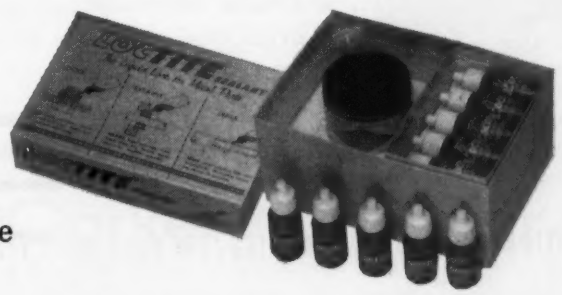
LOCTITE Sealant is easy to apply . . . simple to automate

Labor savings are obtained when several days supply of threaded parts are treated by tumbling with LOCTITE Sealant. Treated parts store for days, lock only when assembled. Smaller quantities may be tumbled by hand in polyethylene bags. Parts may be individually treated using applicator nozzle on LOCTITE bottle or by using continuous feed tube. Parts may be treated *after* assembly, LOCTITE wicks into threads by capillary action.

LOCTITE is a thin liquid that hardens into a tough heat and oil-resistant seal when confined between closely fitting metal parts. It requires no heating or mixing . . . does not air dry. LOCTITE comes fully prepared . . . stores for years . . . hardens only when treated parts are assembled. Ten grades provide any desired torque to all sizes and types of fasteners. LOCTITE-treated fasteners may be removed with ordinary tools . . . fasteners may be re-used.

LOCTITE Kit No. 10-10

Contains 10 grades of Loctite sealant specially put up to assist engineers in determining proper grade of Loctite in product development and for general experimental work. By selection of proper grade, the designer can apply a pre-determined amount of locking torque.



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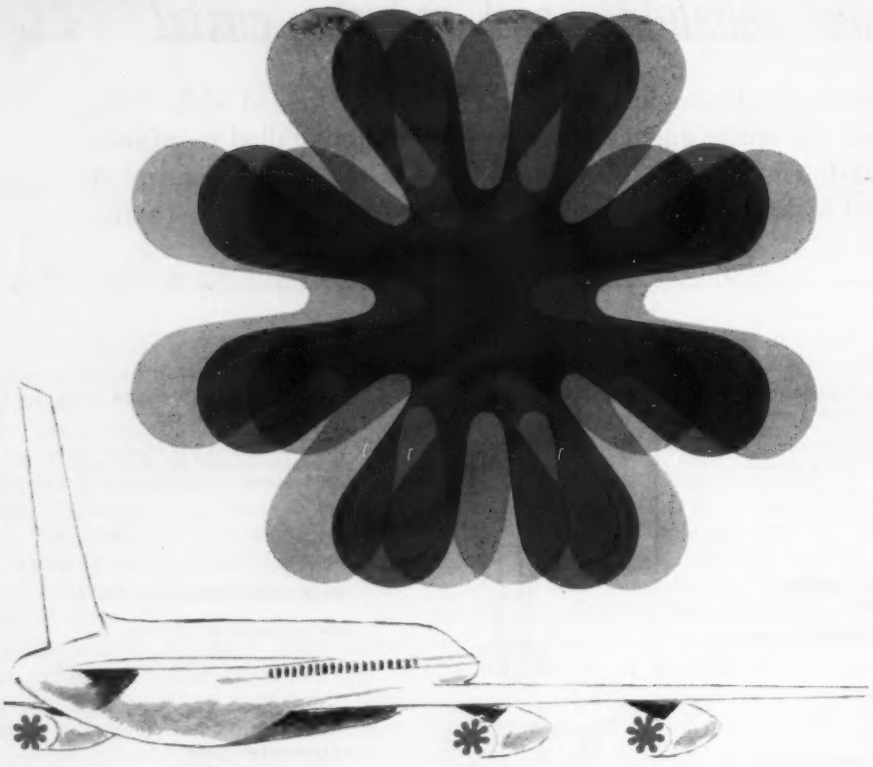

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On jet airliners in flight... or in engine test cells... the slightest hint of unbalance in a jet engine is detected *immediately* by CEC Vibration Pickups.

Three types are offered: the omnidirectional-mounted 4-123, the horizontal 4-121, and the vertical 4-122. All feature constant damping over the operating temperature range of −65°F. to +500°F. These hermetically sealed pickups function perfectly in oily, corrosive, and humid atmospheres. Each weighs only 4.25 ounces. *For complete information, call your nearest CEC sales and service office, or write for Bulletin 1596-X12.*

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CONSOLIDATED ELECTRODYNAMICS / 360 sierra madre villa, pasadena, california

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CIRCLE 4 ON INQUIRY CARD

MACHINE MOVEMENT CONTROL

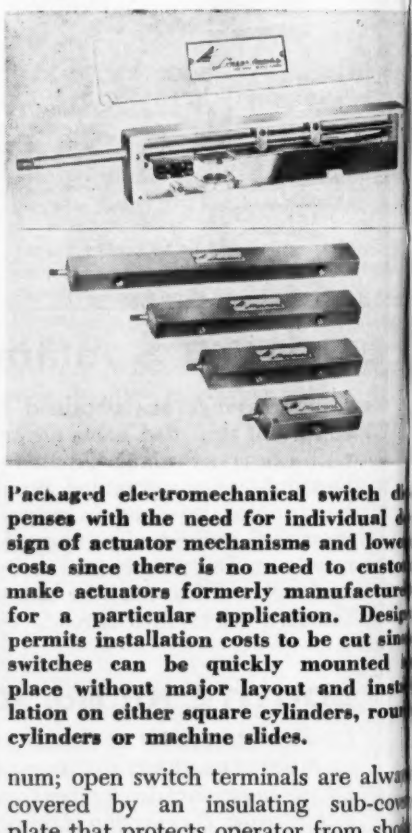
Packaged Switch Saves Design Time

A new standardized line of packaged electromechanical switching units eliminate the need for individual design of actuator mechanisms in the electrical control of linear machine movements.

The design provides self-contained switching units in which two two-circuit double-break snap action switches are operated by adjustable cams mounted on a rigid, heavy-walled sliding actuator tube coupled to an air cylinder or sliding machine member. Movement of the cylinder operates the switches at pre-set points and controls machine members operated electrically through the switches.

Utilization of standardized actuator bars and cams give closer alignment in relation to the mounted switches, and less deflection in the internal action of the switches resulting in longer life.

Designed for wiring through a single conduit, the switch parts are enclosed within a rigid cast housing of alum-



Packaged electromechanical switch dispenses with the need for individual design of actuator mechanisms and lower costs since there is no need to custom make actuators formerly manufactured for a particular application. Design permits installation costs to be cut since switches can be quickly mounted in place without major layout and installation on either square cylinders, round cylinders or machine slides.

num; open switch terminals are always covered by an insulating sub-cover plate that protects operator from shock when cover plate is removed for circuit adjustment.

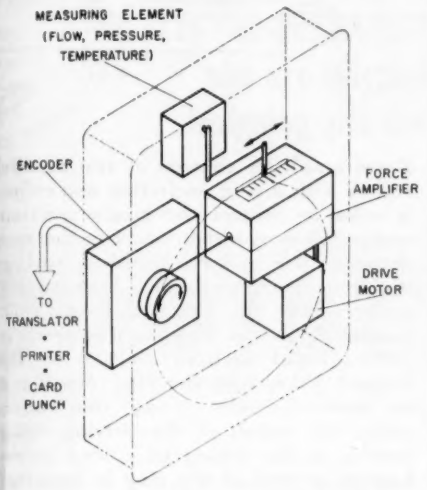
Linear Controls Co., Skokie, Ill. states that five standard units are available for specific stroke length requirements: 0-4″; 0-8″; 0-12″; 0-18″ and 0-24

Circle No. 89 on Inquiry Card

FORCE AMPLIFIER

Mechanical Amplifier Eliminates Electronic Components

A digital transducer that measures process variables and provides digital encoding for flow, liquid level, pressure or temperature employs a completely mechanical force amplifier that eliminates the need for electronic



Schematic illustrates the relationship between the measuring element, force amplifier, and analog digital converter.

servos, vacuum tubes, magnetic amplifiers, or other electronic components. Elimination of these components lowers installation and maintenance costs and increases reliability. Actuated directly by standard measuring elements, the transducer positions the shaft of a precision encoder whose output may be connected to a translater for visual read-out of other equipment for printout, data handling or control.

The heart of the unit is the mechanical force amplifier which can be actuated directly by a primary measuring element such as a mercury or bellows type of manometer for flow or liquid level, a Bourdon tube for pressure, or a filled thermal system for temperature.

Output forces from these primary measuring elements become the input force to the force amplifier. Input forces can be less than 1 gram. The mechanical amplifier increases this force up to 500 times. The linear output motion is identical to the input motion within 0.001 inches. With any fixed input position, a 200 gram load change causes an output error of less than 0.002 inches. Useful travel of the mechanical force amplifier is 2 inches and full scale travel time is variable from 1 to 20 seconds depending upon the driving speed. The force amplifier is completely mechanical and is powered by a small electric motor.

Digital transducers employing the mechanical force amplifier are avail-

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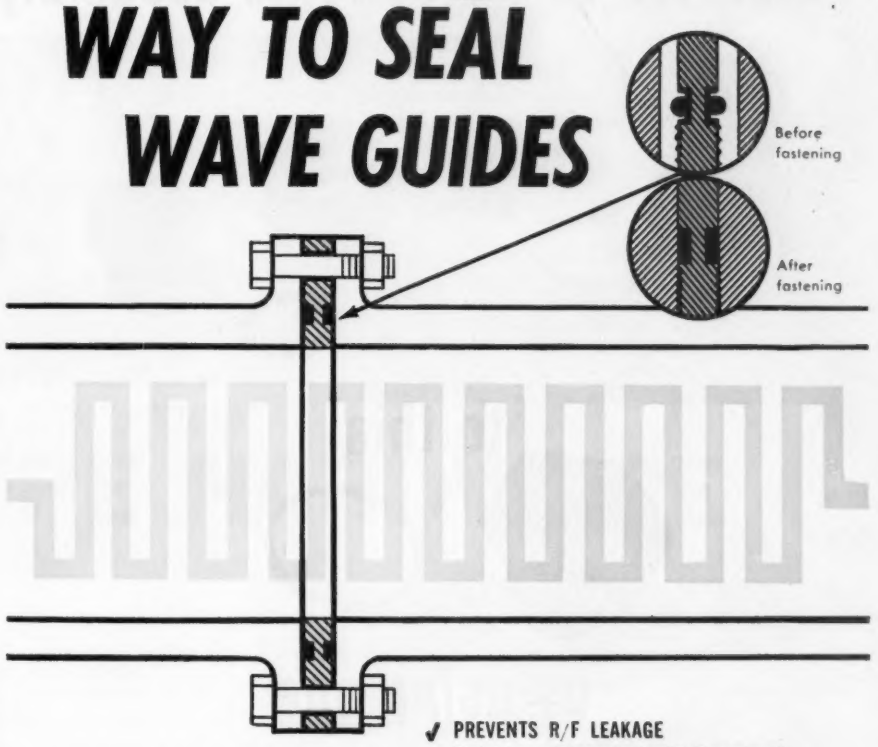
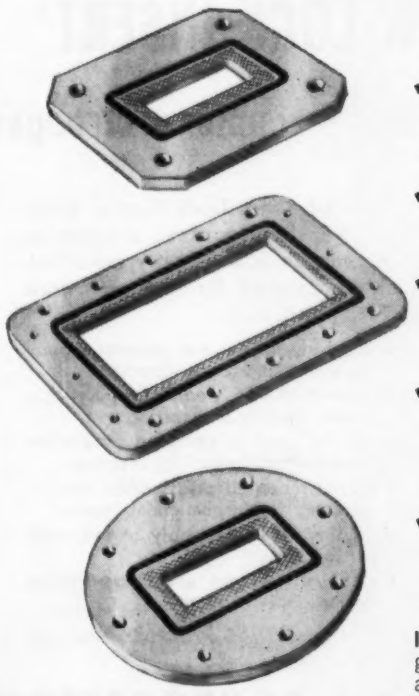




✓ **PREVENTS R/F LEAKAGE**
Metal-to-metal contact with "engraved fingers" on inside surfaces assures electrical continuity.

✓ **PROVIDES NO-LEAKAGE SEALING**
Controlled confinement of seal gland assures safe, sure, positive sealing — **exceeds** top hermetic specs!

✓ **ELMINATES ARCING AND/OR BURNING**
Designed to exacting requirements for proper mating of flanges as specified.

✓ **CAN BE RE-USED**
Seal is never "squeezed" beyond elastic limits, "memory" is constant, before, during and after fastening.

✓ **ECONOMICAL**
Eliminates cleaning or resurfacing flanges, no intricate machining required to accommodate the seal, and they're resuseable with just normal care.

✓ **STANDARDS FOR W/R SERIES**
Electr-O-Seals are available as standards to WR series Wave Guide flanges, assuring adequate supply and economy.

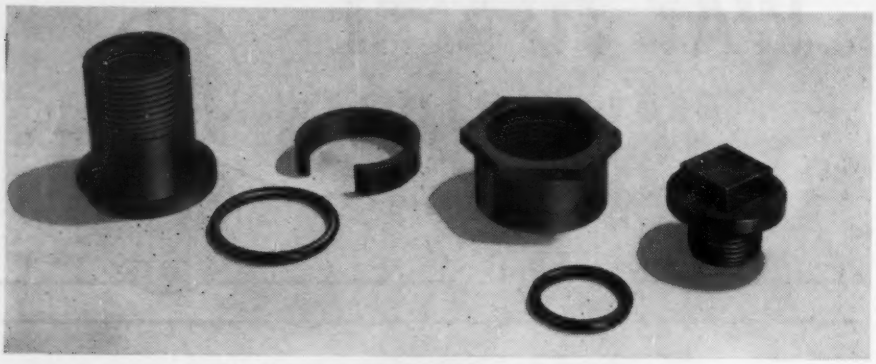
In addition to the standard WR series wave guide flange seals, Parker Seal Company also makes special seals to meet almost any specification or configuration. A nation wide group of field engineers are available to aid in expediting your requirements.

For more complete information send for catalog 5801.

Parker SEAL COMPANY
Culver City, California and Cleveland, Ohio
A DIVISION OF PARKER-HANNIFIN CORPORATION

CIRCLE 5 ON INQUIRY CARD

TEXAS INSTRUMENTS INCORPORATED
simplified this electronic assembly

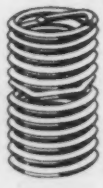


to this

by using one
HELI-COIL® SCREW-LOCK INSERT*

Radar assembly made lighter • simpler • stronger

With only a minor redesign of the magnesium housing—using one *Heli-Coil* Screw-Lock Insert—Texas Instruments simplified this complex 6-piece closure assembly to a simple plug and O-ring. In this and other Texas Instruments applications involving closures, supports and assemblies with threaded fasteners, *Heli-Coil* stainless steel wire thread inserts save weight, space and manufacturing costs, permit extensive use of light-weight magnesium with strong steel threads.



Heli-Coil Screw-Lock Inserts, made of 18-8 stainless steel, provide an *internal lock*, are easily installed, eliminate need for lock nuts, lock wiring and...

- positively lock screws against loosening under impact or vibration
- prevent thread wear, stripping, corrosion, galling and seizing
- can be used in standard proportion bosses without need for redesign
- permit repeated disassembly and reassembly for inspection or service
- simplify screw assembly at inaccessible locations
- meet government specs for locking torque and vibration

*Patented

HELI-COIL CORPORATION
DANBURY, CONNECTICUT

HELI-COIL CORPORATION, 2709 Shelter Rock Lane, Danbury, Connecticut
I'd like more information on *Heli-Coil* Screw-LOCK Inserts

NAME_____ TITLE_____

FIRM_____

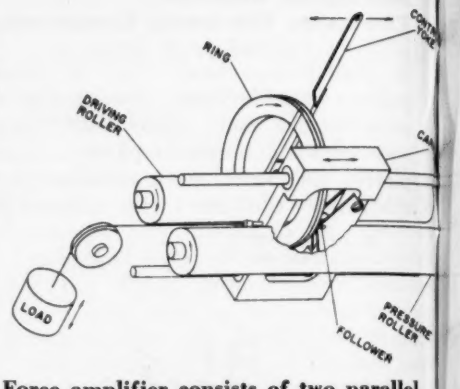
ADDRESS_____

CITY_____ ZONE____ STATE_____ 1585

IN CANADA: W. R. WATKINS CO., Ltd., 41 Kipling Ave., S., Toronto 18, Ont.

CIRCLE 6 ON INQUIRY CARD

COMPONENTS DESIGN



Force amplifier consists of two parallel rollers with a ring encircling one roller, a yoke to control the ring's position, and a follower which contacts the ring between the rollers. Tension springs maintain friction contact between the rollers and the ring, and transmits motion from the ring to the pressure roller. Input motion, applied to the control yoke, tilts the ring causing it to move laterally along the rollers under the action of the driving roller similar to the action of a lead screw. Lateral motion of the ring is imparted to the follower and carriage, located between the rollers, which transmits the output force. When the control yoke moves to a new position and stops, the ring moves laterally along the rollers and assumes a balanced position directly below the yoke's control point. In comparing the force amplifier to a lead screw, note that the angle of tilt of the yoke corresponds to the pitch of the lead screw. As the ring moves towards a balanced position the pitch (angle of tilt) becomes progressively smaller. Since the driving speed is constant, the output force becomes progressively larger as the pitch approaches zero. Thus the amplifier develops its maximum force at the balance or known position, with the force limited primarily by the friction between the ring and the rollers.

able in vacuum and pressure ranges to 10,000 psi, temperature ranges to 600F, and in mercury or bellows type manometers for liquid level or flow applications. These transducers are conservatively rated according to American Meter Co., Inc. with an accuracy of plus or minus 1% of span. Reproducibility is better than plus or minus 0.5% of span.

Circle No. 77 on Inquiry Card

WORTH FILING

Metal stampings and Wire Forms

Complete specifications and illustrations on lugs, clips, terminals and other standard parts.

Source: Zierick Mfg. Co.
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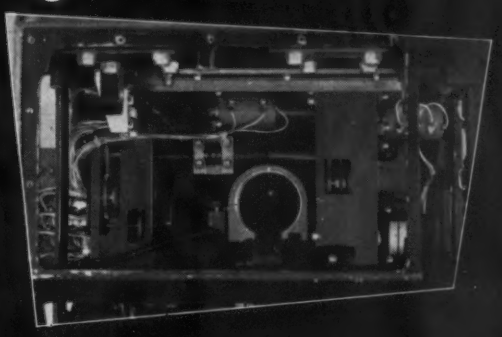
For your copy: Circle No. 161 on Inquiry Card.

To ELECTRO-MECHANICAL ENGINEERS who are interested in designing and developing

PROTOTYPE HARDWARE



1. Portion of Navigational Display Mechanism
2. Flight Interrupter
3. Reticle Frame for Navigational Display
4. Experimental Magnetic Memory Drum

The Hughes Systems Development Laboratories have dozens of openings for Electro-Mechanical Engineers... to design hardware to meet the severe environments of space vehicles, missiles and all-weather interceptors. This is an opportunity for design engineers to utilize their ingenuity and creativity in the development of complex precision electro-mechanical devices which must be highly efficient and reliable.

These positions provide, perhaps uniquely, for individual professional satisfaction through participation in the performance analysis of your own creations.

Some of the areas of assignment are:

- Infra-red Devices
- Digital Computer Devices
- Gyroscopic Guidance Devices
- Inertial Guidance Devices
- Flight Simulator Equipment
- Missile Control Devices
- Antenna Control Devices

Ideally, applicants should have at least two years of practical professional mechanisms experience and an accredited E.E., M.E., or Physics degree.

If you feel that you can contribute, please airmail your resume to:

Mr. Robert A. Martin, Supervisor Scientific Employment
HUGHES RESEARCH AND DEVELOPMENT LABORATORIES
Culver City 75, California

HUGHES

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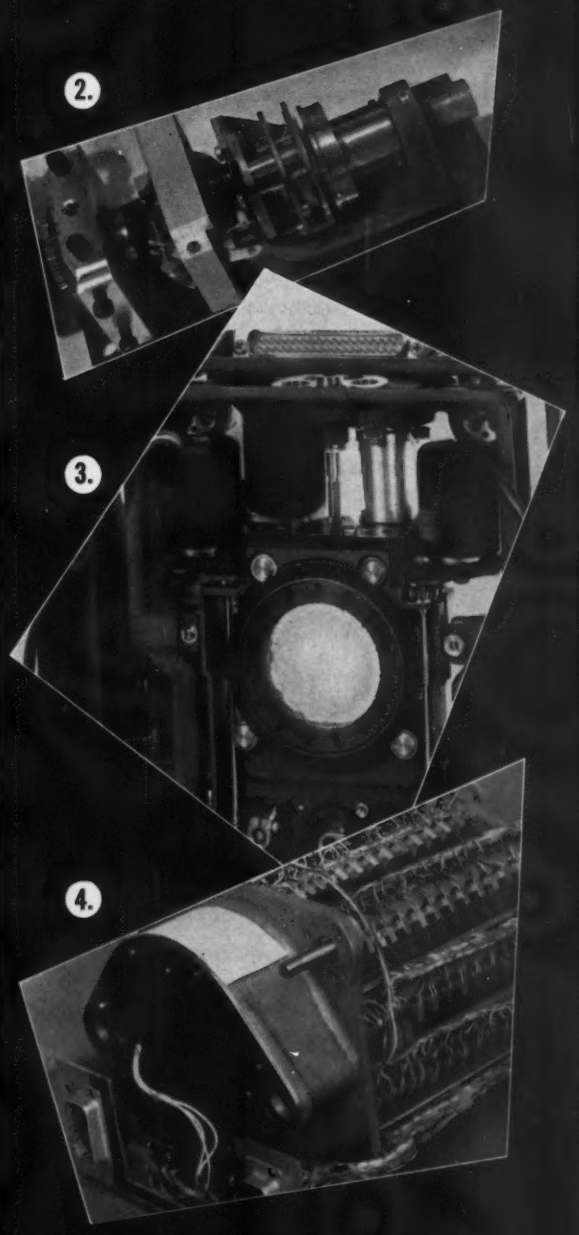


MOTOR BRUSH HOLDERS

Constant-Force Brush Springs Minimize Brush Wear

In all rotating electrical equipment brush pressure is probably the major influence on the rate of brush wear. Excessive friction caused by unnecessarily high brush pressure accelerates mechanical wear while insufficient pressure gives poor contact, causing sparking and heating to increase electrical wear. Ideally, brush pressure should be maintained at a constant, optimum value throughout brush life.

Relationship between unit pressure and frictional and electrical wear rates of carbon brushes are shown in Fig. 1. It can be seen that increasing brush pressure reduces electrical wear but increases mechanical wear. Obviously the best design is to select a brush pressure correponding to the minimum point on the combined wear curve. However, this is difficult to accomplish with conventional brush springs.

Normally the designer selects a higher pressure as the design pressure when using conventional springs. As the brush wears, the deflection of the spring changes and the force the spring exerts decreases. As the brush continues to wear, the constantly diminishing contact pressure reaches, for a brief period, the actual optimum value. However, the brush continues to wear, and the pressure exerted by the spring continues to decrease. Thus electrical wear progresses at an increasing rate until arcing occurs.

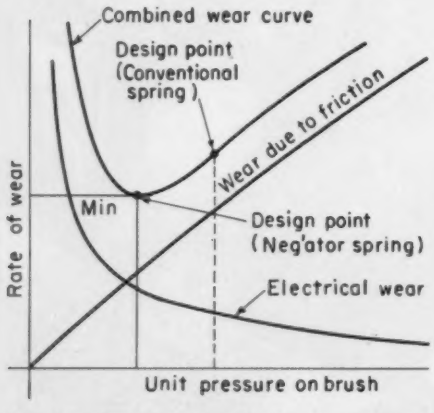


Fig. 1—Combined rate-of-wear curve is the sum of the electrical and mechanical rate-of-wear curves. Optimum brush pressure is the minimum point on the combined curve. Use of constant-force brush spring enables designer to specify optimum brush pressure with assurance that it will remain constant throughout brush life.

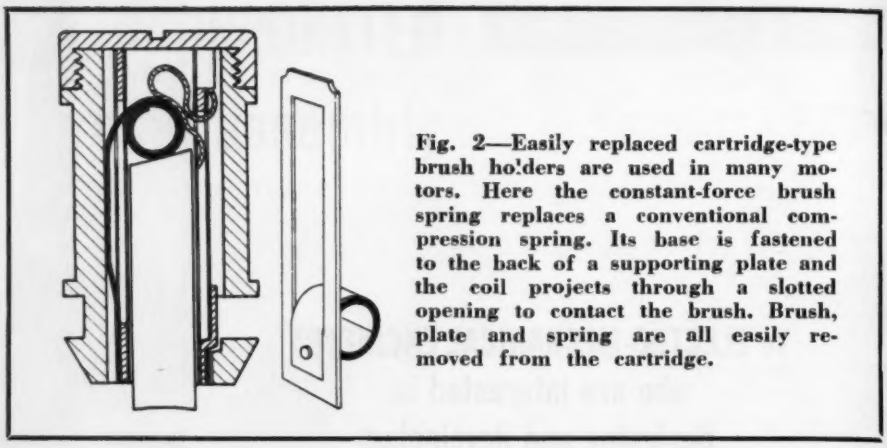


Fig. 2—Easily replaced cartridge-type brush holders are used in many motors. Here the constant-force brush spring replaces a conventional compression spring. Its base is fastened to the back of a supporting plate and the coil projects through a slotted opening to contact the brush. Brush, plate and spring are all easily removed from the cartridge.

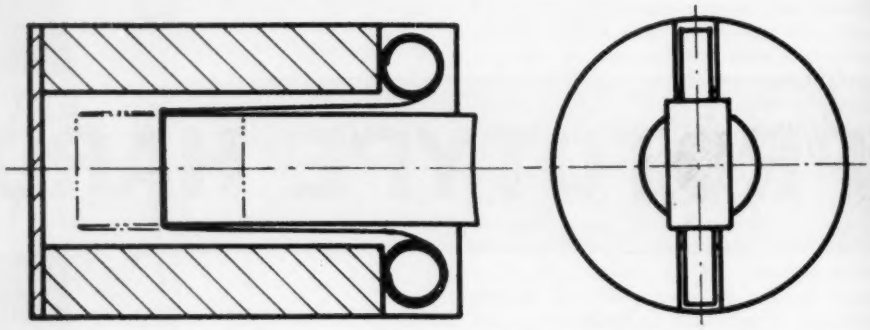


Fig. 3—Small clearance above the brush is a particular problem in many motors. The problem of how to apply brush pressure in such cases is simply and effectively solved with this saddle type arrangement (Fig. 2a) by which the force of two small Neg'ator springs is applied. This saddle design, in which the two springs are formed of one continuous strip of material, is very adaptable to a cartridge type holder (Fig. 2).

This occurrence can be remedied only by frequent spring adjustments, introducing complications into the brush holder design and adding the risk of human error without any assurance that optimum contact pressure will be maintained for more than a small fraction of the operating period.

Recently the constant-force or zero-gradient spring, called the "Neg'ator" by its manufacturer, Hunter Spring Co., Lansdale, Pa., has provided the designer of both large and small electrical motors with means of obtaining optimum pressures throughout brush life. A coil of prestressed spring material, the constant-force spring, is capable of undergoing very large linear deflections with negligible build-up of the restraining force. Thus, spring force is effectively maintained constant throughout the spring's return stroke.

In general, the following improvements in brush life and performance have been experiencd with constant force springs in all types of motors and generators:

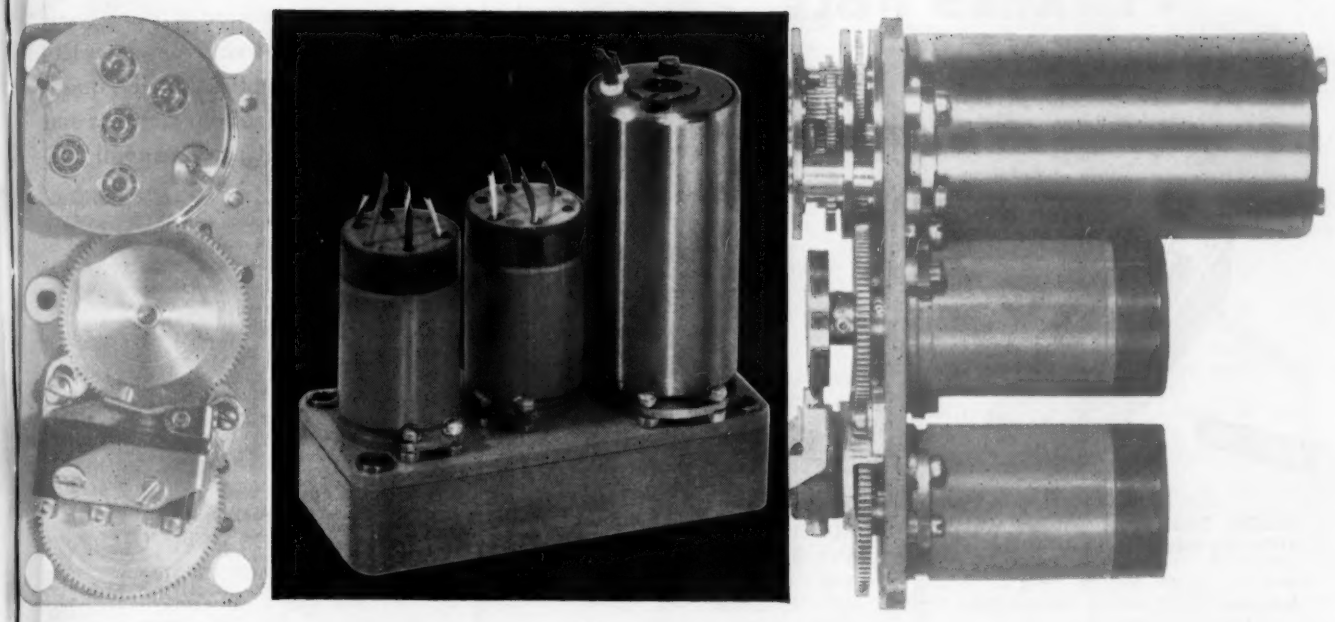
- Constant brush pressure on commutator or slip rings at all times with a minimum of service checks and adjustments.
- Decreased brush wear. In addition, because of simplified brush holder design, more space may be available for longer brushes.
- Elimination of burned brushes or scored ringes resulting from excessive or insufficient brush pressure.
- Reduction of electrical wear caused by arcing. The spring also exhibits efficient tracking at speeds considerably higher than the break-contact speed of conventional springs. This is due to the low mass of the active material and apparent absence of any harmonic frequency.
- Simplified design of both brush spring and brush holder assemblies. Auxiliary parts such as lever arms and spring adjustment assemblies are replaced by a simple back-up plate in most designs. Mounted on brackets or studs the compact holders reduce crowding on bracket arms, facilitate maintenance and inspection and permit mounting of additional brushes on the same commutator ring.

Figures 2 and 3, showing actual constant-force brush spring assemblies in fractional horsepower motors and small generators, illustrate these basic points of improved design and performance. They also show the ingenuity exhibited by designers in using the physical characteristics of these unconventional spring forms, chiefly in the reduction of parts used and in facilitating the removal and replacement of brushes and brush springs.

Circle No. 78 on Inquiry Card

THOMAS A. EDISON

OFFERS YOU SINGLE SOURCE RESPONSIBILITY



FOR SUB-MINIATURE ELECTRO-MECHANICAL SYSTEMS

This sub-miniature, servo-gear train system is designed and manufactured by Edison for use in airborne or ground support equipment. It is one example of Edison's unique ability to supply electro-mechanical systems in one integrated assembly.

Weighing only 9½ ounces this system contains gear train assembly, linear transformer, control transformer and motor generator. Systems such as these can be side or in-line mounted or made in any configuration to meet your requirements.

Edison has complete facilities for designing and manufacturing magnetic amplifiers, computers, transducers, miniature relays servo-motors and gear trains. Unlike other companies who must rely on outside suppliers, Edison offers you single source manufacturing and design responsibility. This is backed by one of the most complete research laboratories in the country, where experienced Edison engineers carry on a continuing program in search of new and improved state of the art designs.

Let the Edison team be your single source for servo components and electro-mechanical systems.

Thomas A. Edison Industries

INSTRUMENT DIVISION

68 LAKESIDE AVENUE, WEST ORANGE, N. J.

EDISON ENGINEERING OFFICES ARE LOCATED IN: CHICAGO; DALLAS; DAYTON; LOS ANGELES

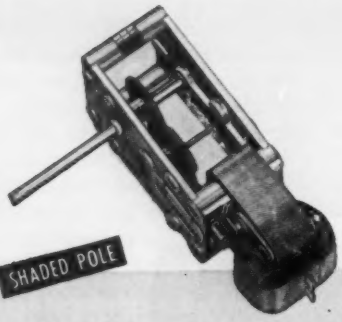
CIRCLE 7 ON INQUIRY CARD

New from HOWARD...a Complete line

- **UNIVERSAL**
- **SHADED POLE**
- **INDUCTION**

Ratios from 3:1 to 2700:1

Shown on these pages are just a few of Howard's gear motors. Thousands of combinations and ratios are available in universal, shaded pole and induction types. If your product requires gear motors, check today for complete information. Give us details of your application and quantities required and we will be happy to submit samples and quotations or more information on standard types available.



SHADED POLE

MODEL 300

TYPE: Two Pole Shaded Pole AC—3200 R.P.M.

WIDTH: 2-15/32". LENGTH: 3-7/8".

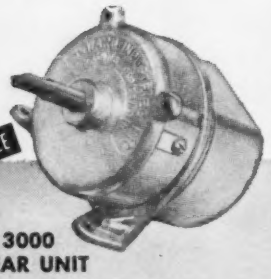
MAXIMUM CONTINUOUS TORQUE OZ. IN. (at 11/16" Stacking Length).
*1 R.P.M. 500 oz. in.
*150 R.P.M. 3.3 oz in.

MAXIMUM INTERMITTENT TORQUE OZ. IN. (at 11/16" Stacking Length).
*1 R.P.M. 750 oz in.
*150 R.P.M. 5 oz. in.

VOLTS: 12 to 115.

BEARINGS: Porous bronze sleeve bearing with oil reservoir.

*Torques at intermittent speeds are inversely proportional to speed.



SHADED POLE

MODEL 3000 with GEAR UNIT

TYPE: 2 Pole Shaded Pole.

DIAMETER: 3-7/16".

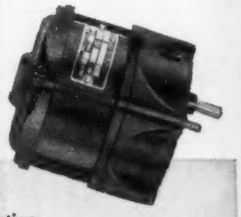
LENGTH: 3-5/8" to 4-1/2".

MAXIMUM CONTINUOUS TORQUE* 1 R.P.M. (at 1-1/2" Stacking Length): 45 in. lbs.

MAXIMUM INTERMITTENT TORQUE* 1 R.P.M. (at 1-1/2" Stacking Length): 70 in. lbs.

BEARINGS: Porous bronze sleeve type with oil reservoir.

*With external fan. Torques at other speeds from 1 to 400 rpm available upon request.



INDUCTION

MODEL 2400

TYPE: 4 Pole Induction.

DIAMETER: 2-9/16" square.

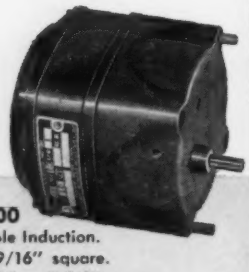
LENGTH: 2-3/8" to 3".

SINGLE PHASE CAPACITOR MOTOR:
Maximum Torque oz. in.—1.
Full Load Speed R.P.M.—1150.
Bearings—RBC—Ball. RWC—Sleeve.

TWO PHASE MOTOR:
Maximum Torque oz. in.—1.5.
R.P.M.—1150.
Bearings: RBT—Ball. RWT—Sleeve.

BEARINGS: Porous bronze sleeve type with oil reservoir, or grease sealed ball bearings.

GEAR UNITS: Ratios 6:1 to 3600:1. Spur gears throughout. The high speed pinion is cut on the shaft, assuring accuracy and concentricity, and maximum strength is achieved by supporting the output shaft in large porous bronze bearings.



INDUCTION

MODEL 2500

TYPE: 2 or 4 Pole Induction.

DIAMETER: 2-9/16" square.

LENGTH: 1-7/8" to 2-3/8".

SPEED: *1200 to 3600 R.P.M.

H.P.: 1/300 to 1/1400.

MAXIMUM TORQUE oz. in. *1.6 to 3.5.

BEARINGS: *Ball or sleeve.

*Dependent on type of motor used; i.e. Non-Synchronous Capacitor Motors, Torque Motors, Standard Synchronous Motors, Hysteresis Synchronous Motors.

GEAR HEAD: Ratios from 6:1 to 3600:1. Torques up to 300 in. oz. at low speeds. Range of output speeds from ½ r.p.m. to 600 r.p.m.

Spur gears are used throughout. The high speed pinion, cut on the rotor shaft, assures extreme accuracy, and maximum strength is achieved by supporting the output shaft in large, solid bronze bearings.

INDUCTION

MODEL 2900 with GEAR UNIT

TYPE: 2 Pole, 4 Pole Induction.

DIAMETER: 3-5/16".

LENGTH: 7-5/64" to 8-11/64".

SPEED: 1650 to 3600 R.P.M. depending on type of motor used—Non-Synchronous, Standard Synchronous, Hysteresis Synchronous, or Torque.

H.P.: 1/70 to 1/15 depending on length of stacking.

TORQUE OUTPUT: Up to 60 in. lbs. depending on ratio.

BEARINGS: Permanently lubricated and sealed ball bearings.

RATIOS: 10:1 to 60:1.

UNIVERSAL

MODEL 29-500 with GEAR UNIT

TYPE: Universal AC/DC or Shunt.

DIAMETER: 3-5/16".

LENGTH: 7-13/64" to 7-37/64".

SPEED: 5000 to 10,000 RPM.

H.P.: 1/70 to 1/4 depending on length of stacking.

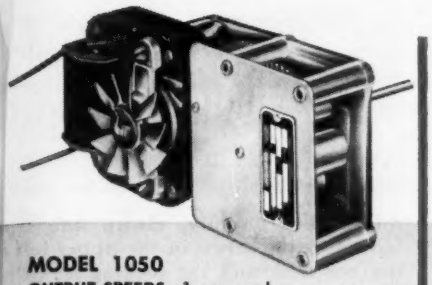
TORQUE OUTPUT: Up to 60 in. lbs. depending on ratio.

BEARINGS: Permanently lubricated and sealed ball bearings.

RATIOS: 10:1 to 60:1.

line of Fractional H.P. Gear Motors

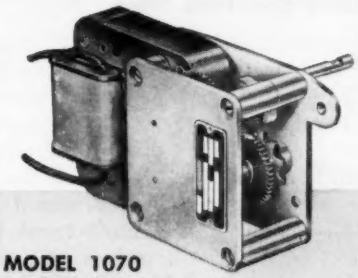
2 POLE, DOUBLE BEARING



MODEL 1050

OUTPUT SPEEDS—1 rpm and up.
GEARS—Molded nylon in high-speed for quiet operation, stamped, cut or sintered in low-speed section.
BEARINGS—Sintered porous bronze with large oil reservoirs for assured self lubrication.
MOUNTING—Front only; choice of ten holes tapped as required.
ROTATION—Unidirectional (CW or CCW).
SHAFT—3/16 in. dia. std. with length to meet requirements.

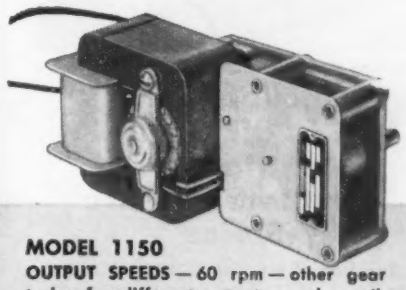
starting torque, in. lbs.	no load rpm	full load					stack A, in.
		torque, in. lbs.	rpm	input (115-V) amps.	input (115-V) watts	gear ratio	
20	6.8	33	6	.34	18	500:1	⅝
15	10.2	24	9	.34	18	333:1	⅝
7	17	19	15	.46	24	200:1	⅝
5	43	11	30	.46	24	100:1	⅝
2.25	75	4.5	68	.46	24	45.4:1	⅝
2.0	122	2.4	108	.75	35	27.8:1	⅝
1.5	159	1.9	140	.81	40	21.4:1	⅝



MODEL 1070

OUTPUT SPEEDS—30 rpm and up.
GEARS—Molded nylon in high-speed section for quiet operation; stamped, cut or sintered in low-speed section. Also available, when specified, with cut gears throughout.
BEARINGS—Sintered porous bronze with large oil reservoirs for assured self-lubrication.
MOUNTING—Front only; choice of three holes tapped #8-32 and/or two .161 in. dia. holes.
ROTATION—Unidirectional (CW or CCW) as specified.
SHAFT—3/16 in. dia. std. with length to meet requirements

starting torque, in. lbs.	no load rpm	full load					stack A, in.
		torque in. lbs	rpm	input (115-V) amps	input (115-V) watts	gear ratio	
2.25	82	4.5	74	.46	24	37.8	⅝



MODEL 1150

OUTPUT SPEEDS—60 rpm—other gear trains for different output speeds available, state requirements.
GEARS—Molded nylon in high speed section for quiet operation. Stamped, cut or sintered for low-speed section.
BEARINGS—Sintered porous bronze with large oil reservoir for assured self-lubrication.
MOUNTING—Front only, choice of ten holes tapped as required.
ROTATION—Unidirectional (CW or CCW as specified).
SHAFT—1/4 in. dia. std. with length to meet requirements.

starting torque, in. lbs.	no load rpm	full load *					stack A, in.
		torque, in. lbs.	rpm	input (115-V) amps.	input (115-V) watts	gear ratio	
16	75	24.5	60	3.1	124	50:1	1¼

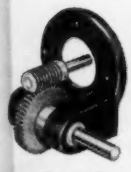
*Intermittent duty (10 seconds On, 50 second OFF continuously).

GEAR REDUCTION UNITS

Designed for direct mounting on Howard motors, the speed reducers illustrated in this section give a wide range of speeds and torque in both open and closed types; single or two stage. Closed units are grease packed for efficient lubrication with minimum maintenance. For heavy duty, high torque applications, Models A-7 and A-12 are especially recommended. *Twelve Howard universal motors (not shown) are available as gear motors with the gear units illustrated.*

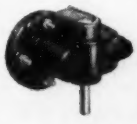
Hundreds of standard ratios permit accurate selection of output speed. Most of the gear units can be supplied with double shaft extensions where required. Our gear reducers are intended for use only with Howard motors.

Ratings are maximum under ideal operating conditions. Each application requires careful consideration based on having description of Load & Duty Cycle.



MODEL A-1
Single Reduction, Open
Maximum Ratio: 58:1
Minimum Ratio: 3:1
TORQUE
Continuous Duty: 5 in. lbs.
Intermittent Duty: 10 in. lbs.
Efficiency: Max. 45%

MODEL A-3
Double Reduction, Open, With Mounting Pad
Maximum Ratio: 2700:1
Minimum Ratio: 40:1
TORQUE
Continuous Duty: 5 in. lbs.
Intermittent Duty: 10 in. lbs.
Efficiency: Max. 30%

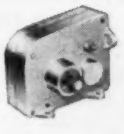


MODEL A-4
Single Reduction, Closed
Maximum Ratio: 58:1
Minimum Ratio: 3:
TORQUE
Continuous Duty: 5 in. lbs.
Intermittent Duty: 10 in. lbs.
Efficiency: Max. 45%

MODEL A-5
Double Reduction, Closed
Maximum Ratio: 2700:1
Minimum Ratio 40:1
TORQUE
Continuous Duty: 10 in. lbs.
Intermittent Duty: 20 in. lbs.
Efficiency: Max. 30%

MODEL A-6
Single Reduction, Closed
Maximum Ratio: 60:1
Minimum Ratio: 3:1
TORQUE
Continuous Duty: 12 in lbs.
Intermittent: 25 in. lbs.
Efficiency: Max. 65%

MODEL A-7
Double Reduction Closed, Heavy Duty
Maximum Ratio: 2600:1
Minimum Ratio: 21.5:1
TORQUE
Continuous Duty: 50 in. lbs.
Intermittent Duty: 100 in. lbs.
Efficiency: Max. 50%



MODEL A-12
Combined Worm and Spur Gears
Maximum Ratio: 525:1
Minimum Ratio: 6.7:1
TORQUE
Continuous Duty: 100 in. lbs.
Intermittent Duty:: 250 in. lbs.
Efficiency: Max. 50%

MODEL A-26
Single Reduction, Closed
Heavy Duty
Maximum Ratio: 60:1
Minimum Ratio: 3:1
TORQUE
Continuous Duty: 50 in. lbs.
Intermittent Duty: 100 in. lbs.
Efficiency: Max. 80%

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HOWARD INDUSTRIES, INC., 1796 State St., Racine, Wis., Telephone ME 2-2731, Teletype: RAC344

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CIRCLE NO. 8 ON INQUIRY CARD

SPECIAL REPORT ON SYNCHROS:

Induction Motors of California Size 8 Synchro

Induction Motors of California Manufactures Complete Synchro Series

A full line of size 8 (.750" diam.) and size 11 (1.062" diam.) synchros, resolvers and linear tranformers for indication and control are manufactured by Induction Motors of California, Maywood, California, in general accordance with MIL-S-20708.

GENERAL SPECIFICATIONS FOR TYPICAL SIZE 8 SYNCHROS

26 VAC 400 CPS

± 7' MAXIMUM ERROR
30 MV MAXIMUM NULL

IMC TYPE	INPUT (MA)	PHASE SHIFT (DEGREES)	OUTPUT (VOLTS)
Torque Transmitter			
9708-002	150	12	11.8
008-235	100	8	11.8
Control Transformer			
9708-003	120	12	23.5
9708-007	7	17	22.5
008-334	29	8	22.5
Resolver Transmitter			
9708-004	50	22	10.4
Linear Transformer			
9708-005	110	10	18.0
Control Differential			
9708-006 (Rotor Primary)	100	12	11.8

Detailed Specifications Available Upon Request

OVER 100 DESIGNS AVAILABLE

Induction Motors of California has over 50 standard Size 8 designs. Any of these may be furnished with electrical or mechanical variations to suit your particular application.

Over 50 standard Size 11 synchro designs, including Navy BuOrd types, have been produced to meet exact customer requirements. A typical group of 115V and 26V BuOrd synchros immediately available are:

11CT4b 11CX4b 11CDX4b 11TX4b 11TR4b

Specifications on synchro components, as well as complete information on step-servo motors and solenoids manufactured by our company, are available when requested on company letterhead.

Induction Motors of California

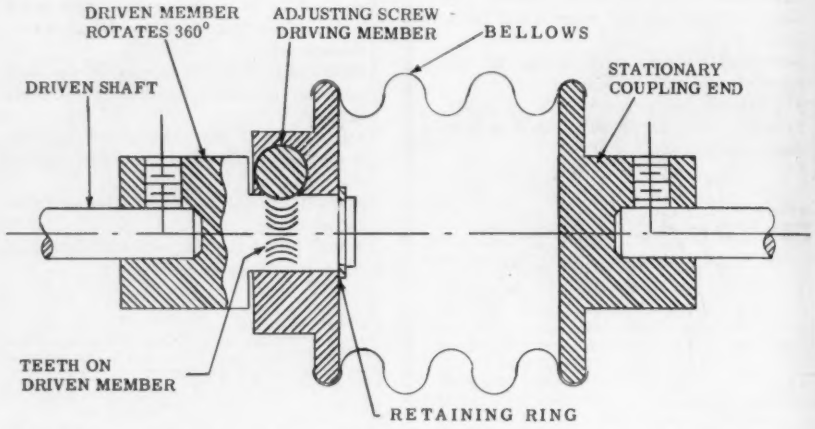
DIVISION OF
IMC MAGNETICS CORP., N.Y.
6060 Walker Avenue, Maywood, California
LUdlow 3-4785
Representatives in principal cities
CIRCLE 9 ON INQUIRY CARD

PHASE COUPLING

Phasing Synchros Fast

Two synchro units are normally phased by loosening the stator of one synchro in its mounting and gradually rotating it in relation to the other synchro stator – a difficult procedure when synchros are not readily accessable. A phase adjusting coupling, designed by N. Raskhodoff and manufactured by P. I. C. Design Co. solves this and similar problems. Mr. Raskhodoff's basic design objectives were:

Adjustable coupling, clamp hub type, has adjusting screw in the upper left of the coupling and the locking screw below. Overall length less than 1⅞".



Adjustable shaft coupling hub, serving as the driven member has a reduced diameter section which rotates within the coupling end attached to one of the bellows. The adjustable screw, serving as the worm and the driving member, and the locking screw are positioned in this coupling end. Small retaining rings on the adjustable shaft coupling hub and the adjustable screw allow rotation without longitudinal motion. Special technique adopted in the forming of the teeth on the periphery of the driven member thus making it possible to locate the teeth where required for best space use.

• To produce a coupling in which one coupling shaft end could be rotated relative to the other coupling shaft end through 360 degrees, or "phased" by an adjustment screw providing a very precise angular rotation of the adjustable shaft coupling end relative to the opposite shaft coupling end which remains stationary.

• To have the adjustable feature adaptable to various types of couplings, not to the bellows type alone.

• To achieve the adjustable feature at as small an increase in coupling size as possible.

One of the more difficult problems was to achieve the adjustable feature with a minimum number of parts and thereby attain lower production cost and selling price comparable to a coupling without adjustable means.

The cross-sectional drawing demonstrates how Mr. Raskhodoff fulfilled these objectives in the design of a bellows type coupling. Installation of this adjustable phasing coupling between synchros permits phasing of one synchro rotor relative to the other with accuracy and ease, eliminating the synchro stator adjustment.

Rotation of the adjusting screw one eighth of a turn rotates the adjustable shaft coupling hub end only about 1½°, an advantage where precise adjustment is required.

Circle No. 87 on Inquiry Card

WORTH FILING

Resistance Devices

New catalog covers general line of stocked resistors, controls and resistance devices, including listings, such as tab-mount controls used in servoing, and new miniaturized wire-wound series 57 precision potentiometers (one ½" in diameter and weighing ¼ oz.

Source: Clarostat Mfg. Co., Inc.
Dover, New Hampshire

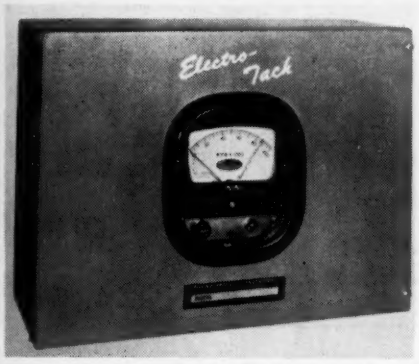
For your copy: Circle No. 194 on Inquiry Card

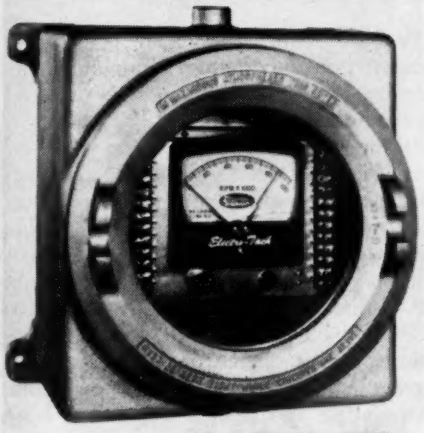
LOW-COST SPEED CONTROL

Transistorized Tachometers With Meter Relay Control

A new type of tachometer with the dual function of measuring speed without physical loading and control of associated circuitry, such as overspeed and underspeed control circuits, provides speed control never before available at a comparable cost, according to the manufacturer.

Sensing device for the tachometer is a magnetic pickup. Angular velocity of shaft projections or a rotating gear



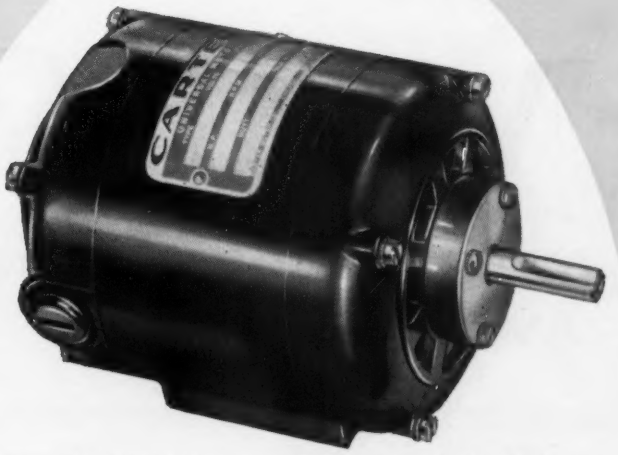


Transistorized Tachometers measure speed in rpm without physical loading and also activate associated circuitry when preset value of rpm is reached. Unit shown at left is mounted in JIC-type enclosure, and unit at right is housed in an explosion-proof enclosure. These are two of a variety of models available.

induce a signal in the pickup corresponding to frequency of revolution. The pickup's signal is converted by the transistorized tachometer to a d-c current directly proportional to the frequency of the pickup's signal. Instantaneous readings in addition to control circuitry are provided by a meter-relay unit whose scale is calibrated in rpm units. Accuracy of indication is 2% of full scale.

The meter has two pointers. One indicates rpm. The other, a control pointer, can be set prior to making a

New Carter Classic™ UNIVERSAL AC/DC Motor



. . . from the NEW Source of fine specialty Motors . . . CARTER . . . with a background of over 25 years experience

Totally NEW . . . and engineered to the highest standards of mechanical and electrical excellence . . . the CARTER CLASSIC FHP motor incorporates all the advances in materials and manufacturing techniques developed in recent years.

PRECISION DIE CAST CONSTRUCTION

Armature, frame and brackets . . . in fact every component has been expertly created to provide a totally NEW quality motor, not a composite of existing parts or old design. Super-precision, sealed ball bearings, no lubrication necessary.

Larger brushes provide performance beyond normal requirements, reduce maintenance. Standard mounting plate can be furnished. Speed governor available.

8 NEW MODELS TO CHOOSE FROM

H.P.	1/35	1/25	1/20	1/15	1/20	1/18	1/12	1/10
R.P.M.	3600	5000	7500	10000	3600	5000	7500	10000

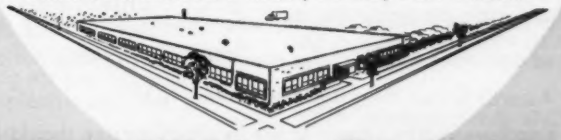
Overall size 4½" x 3⅝" x 3⅜" high. Weight 3¾ lbs.

Available as universal, shunt or series motors from 12v. to 220v. input.

The CLASSIC is produced in the sparkling new Carter factory, designed expressly for efficient, economical motor production and is backed by more than a quarter century motor building experience. Fast delivery, personal attention, complete engineering service. Standard models modified to your application.

You can rely on this dependable new motor source to power YOUR products. A line so distinctive, so superior, you too will say "It's CLASSIC". Low cost will surprise you . . . pleasantly.

WRITE FOR CATALOG SHEET, PRICES, FULL DETAILS



Carter Motor Company

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Large Enough To Serve You . . . Small Enough To Want To!

SALES OFFICES IN PRINCIPAL CITIES OF THE WORLD

CIRCLE 10 ON INQUIRY CARD

MA59
MINIATURIZATION AWARD

Miniature Precision Bearings, Inc., cordially invites you to participate in the 1959 Miniaturization Award competitions. The Miniaturization Award for 1959 will be presented during the spring of 1960 at the 3rd Annual Awards Dinner in New York City. The Award symbolizing Miniaturization is a bronze sculpture by a leading American artist. Certificates of Excellence will also be awarded for additional outstanding entries.

PURPOSES

In addition to stimulating public knowledge in the industrial advancement of miniaturization, the MA 59 competition promotes national recognition of award winning companies, individuals, or organizations.

JUDGING OF ENTRIES

Entries will be judged by an independent committee of members of the electronics, metalworking, research and publishing fields.

ENTRIES

For a brochure giving criteria, upon which the entries are judged and other details of the competition, write Miniaturization Awards Committee, Box 604, Keene, N.H.

This brochure outlines the manner in which entries should be submitted and gives information on past winners. Because entries should be received by January 20, 1960, prospective entrants should secure the MA 1959 brochure as soon as possible.

CIRCLE 11 ON INQUIRY CARD

measurement to any value of rpm desired. When the pointer indicating rpm reaches the value at which the control pointer has been set, a mechanical and electrical contact between the two pointers is made, which activates a relay for controlling asociated circuitry. The relay contacts are connected to a convenient front panel male receptacle or terminal strip to facilitate connection to circuitry being controlled.

In all models, a holding coil circuit keeps contact between indicator pointer and control pointer closed regardless of any subsequent changes in actual value of rpm. A pushbutton switch for releasing this contact is available either mounted on the tachometer's front panel or adapted for mounting at a remote location. An automatic release can be provided instead of the pushbutton if required. Electro Products Laboratories, Chicago, Ill.

Circle No. 93 on Inquiry Card

Displacement Transducers

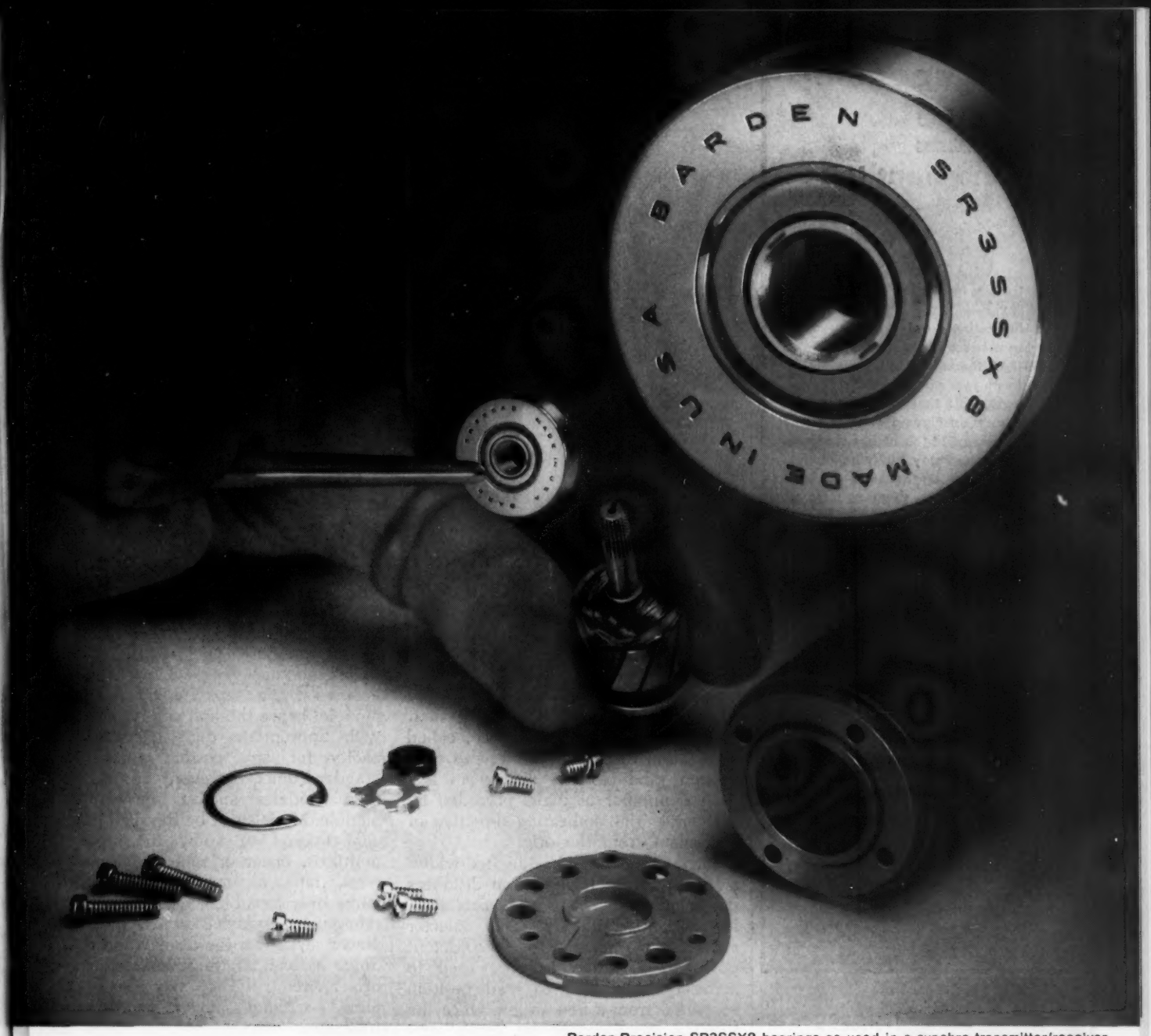
Two models of Sanborn linear displacement transducers are complete units ready for connection to the required preamplifier and input source. These differential transformers are encased in stainless steel shields and have carbide tipped, spring-return contact rods, 10 foot integral cable and suitable adapters. Both models have a maximum stroke of ±0.050″ (0.100″ total); 0.5% linearity; and operate from 5 volts, 2400 cps excitation. Resolution is infinite and a choice of 100, 25, or 10 gram contact pressures is available. Operating and design features of both models include stainless steel bodies and contact rods; jeweled bearings; carbide tips on contact rods. Contact rods are threaded on the exposed end for direct connection to mechanical linkage. Sanborn Company, Waltham, Mass.

Circle No. 234 on Inquiry Card

Low Power Ferrite Isolator

Low power Ku-Band ferrite isolator designed to improve the performance of a klystron excited system, provides a minimum isolation of 25.0 db with an insertion loss of no more than 0.45 db across the band from 16.0 KMc/s to 17.0 KMc/s with a VSWR of 1.12 maximum. It is rated at 5 watts average power, weighs 2.9 ounces and is 0.66 inches in length. Raytheon Company, Special Microwave Devices Subdivision, Waltham, Mass.

Circle No. 236 on Inquiry Card



Barden Precision SR3SSX8 bearings as used in a synchro transmitter/receiver.

BARDEN *functional testing assures precision performance*

The SmoothRator, an electronic performance tester, was developed by Barden to check vibration as a measure of overall functional quality. A standard quality control instrument at Barden, the SmoothRator is also used by many leading component and systems manufacturers.

Precision-built synchros require small, uniform air gaps and consistently low torque to provide accurate response to a generated signal.

Barden Precision low torque bearings assure the required air gap by close control of radial play and concentricity. The SR3SSX8 has an extra large O.D. which eliminates the need for end caps, increasing air gap accuracy and reducing synchro complexity and cost.

From research and design, through quality controlled production, functional testing and application engineering each *Barden Precision* bearing is planned for performance. *Barden Precision* means not only dimensional accuracy but performance to match the demands of the application.

Barden Precision bearings must pass rigid functional tests on the SmoothRator, the Torkintegrator and other Barden-developed or standard test devices. This functional testing is your assurance of consistent precision performance.

Your product needs *Barden Precision* if it has critical requirements for accuracy, torque, vibration, temperature or high speed. For less difficult applications, Barden *predictable* performance can cut your rejection rates and teardown costs.

THE BARDEN CORPORATION

71 East Franklin Street, Danbury, Connecticut

Western office: 3850 Wilshire Boulevard, Los Angeles 5, California

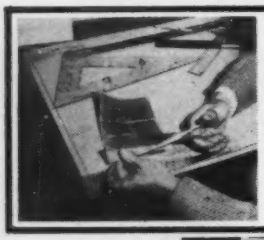
SPECIFY BARDEN PRECISION BALL BEARINGS FOR: INSTRUMENTS • AIRCRAFT ACCESSORIES • COMPUTERS AND RECORDERS • MACHINE TOOL AND TEXTILE SPINDLES • OTHER PRECISION APPLICATIONS

CIRCLE 12 ON INQUIRY CARD

are you spending $12.00 for a one cent job?

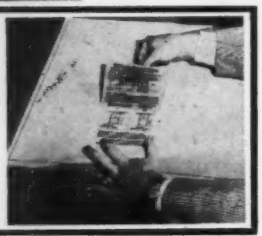
If you're duplicating drawing details, you're squandering precious hours of costly drafting time. STANPAT, the unique tri-acetate that is pre-printed with your standard and repetitive blueprint items, cuts time involved from 3 *hours to 15 seconds!* Figured at current pay rates, this means a $12 job at less than one cent . . . the STANPAT way. Easily transferred to your tracings by an adhesive back or front, STANPAT relieves your engineer of time-consuming and tedious details, freeing him to concentrate on more creative work.

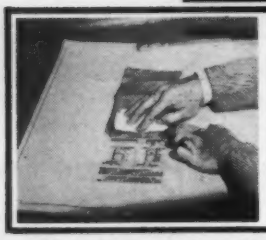
here's how simple the STANPAT method is!



PEEL the STANPAT from its backing.

PLACE the STANPAT into position on the tracing.





PRESS into position . . . will not wrinkle or come off.

STANPAT is available in two types of adhesive backs:

- Rubber base for standard drafting and tracing papers
- Resin base to prevent leaching for papers that contain oils

But whatever the application may be, there's a STANPAT product for your specific needs. Stanpat has a guaranteed shelf life of one year from date appearing on tab end. For further information and technical assistance, complete the coupon below and mail.

STANPAT CO. Whitestone 57, N. Y., U. S. A.
Phone: FLushing 9-1693-1611

☐ Please quote on enclosed samples.
☐ Kindly send me STANPAT literature and samples. Dept. 134

Name_____
Title_____
Company_____
Address_____

CIRCLE 13 ON INQUIRY CARD

ANALOG-DECIMAL CONVERSION

Decimal Readout Device Has Adjustable Zero Reference

Straight decimal display of position of a rotary or linear moving member, with respect to any arbitrary preselected origin, can now be produced from shaft position data of a binary shaft encoder. The electronic device, called a Zerotron, that accomplishes this conversion produces the display in any desired number of digits preceded by a + or − sign indicating direction of movement from the origin.

Digits are 1″ high backlighted white-on-black figures legible from distances up to 20 feet. The manual origin selector consists of a row of selector switches (one per digit) with 10 detent positions. The switches are used to zero-set the display to read position measured from a new origin. Once the selector switches are set for a preselected reference point, Zerotron circuitry automatically performs the offset calculation throughout the travel of the moving member. The original zero reference is retained in the Zerotron memory no matter how often a new reference is selected and even following power failures.

Input to the Zerotron, developed by Norden's Data System Dept. at Gardena, Cal., is from a Norden or equivalent binary shaft encoder slaved to the moving member. The digital binary coded signal indicating position is presented in parallel to the Zerotron circuitry. A relay matrix in the device, in effect a subtractor, performs a parallel digital substraction for each digit of the dimension fed to it. The position display converts the binary coded decimal to a 1-out-of-10 decimal reading. The difference between the absolute analog-to-digital converter reading and the setting of the manual origin selector switches appears on the display in straight decimal form.

Zerotron derives its flexibility from its all-modular design. Each digit is handled by a separate transistorized module; hence the unit can be supplied with appropriate digit handling capacity for any custom application. Standard units, however, consist of six digit modules and a plus-or-minus module. Models can be supplied in any configuration to apply to single or multiaxis, linear or rotary motion systems, tape or manually controlled. Units are available as complete zero-reference display systems including power supply for the display and transducer as well as transducer logic and driver circuitry. They may also be obtained without power supply and transducer circuitry where these already exist in a system.

Circle No. 79 on Inquiry Card

Electronic Counter

A new electronic counter with a uniform 8-decade numerical readout, Model 524D, delivers direct, instantaneous and automatic readings without calculation or interpolation. The instrument, Model 524D, has a crystal oscillator stability of 3 parts in 10^8 short term; 5 parts in 10^8 per week. It provides for full frequency measurements from 10 cps to 10 MC and period measurements from 0 cps to 10 KC. Inexpensive plug-in units extend the frequency measurement range to 220 MC, permit period measurements over 10,000 periods, and increase sensitivity for precise measurement of weak signals. Another plug-in provides for time measurements from 1 microsecond for 100 days. Hewlett-Packard Company, Palo Alto, Cal.

Circle No. 186 on Inquiry Card

It takes a TEAM
to solve timing problems

The control of time is an extremely complex science that demands a thorough knowledge of many individual technologies. For this reason, Haydon maintains a team of engineering specialists to provide the reservoir of skill, knowledge, experience, and creative ability necessary to solve industry's timing problems.

When you submit a timing problem to Haydon, it's handled by a team of specialists — *not* an individual engineer. And you can be sure the Haydon Timing Team is equipped with all the electric, electronic, mechanical and manufacturing know-how needed to analyze your requirements and develop the best possible new or modified timing unit for your specific application.

Correctly designed and efficiently manufactured, Haydon timing devices are exhaustively tested before release to a customer. The results are uniformly high quality devices that are known for fine performance, and long life. May we put our Timing Team to work for you?

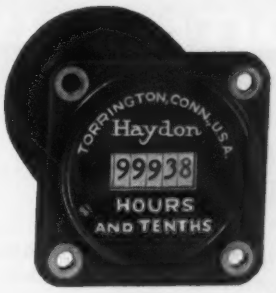
A few units from the complete Haydon line are shown at the right. Send now for further information, outlining your requirements.

Haydon
AT TORRINGTON

DIVISION OF
GENERAL TIME CORPORATION

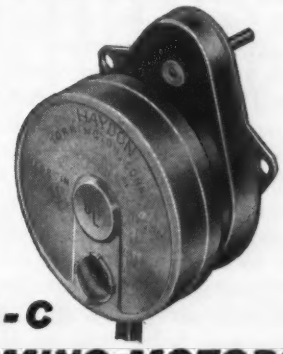
2833 EAST ELM STREET
TORRINGTON, CONNECTICUT

Headquarters for Timing



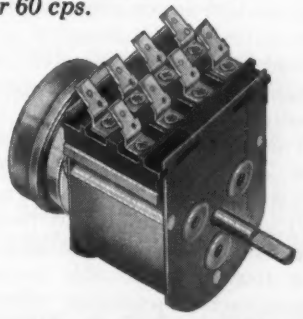
ELAPSED TIME INDICATOR ED-71

Compact, low-cost instrument for machine tools, communications equipment and other commercial applications where an accurate record of operating time is desired. Time Registered: 9,999.9 hours. Weight: 5 oz. Voltages: 120 or 240 v, 60 cps. Power Required: 2.5 watts at 120 v, 60 cps.



A-C TIMING MOTORS

A complete line of synchronous, compact timing motors, speeds from 1/60 to 60 rpm. Guaranteed torques from 6 ounce-inches to 30 ounce-inches at 1 rpm. Voltage ranges 103-132 and 206-264 vac, 50 or 60 cps.



INTERVAL TIMER

Directly controls heavy duty electrical loads. Type AD can be supplied with up to 3 SPST switches. Type AT has 1 SPST switch only. Intervals available with dial and knob: 15, 60 and 180 minutes. Intervals to meet your specific requirements can be supplied. Voltages: 120 or 240 v, 50 and 60 cps. Switch Rating: 28 amps, 250 vac non-inductive; 1 hp, 240 vac.

CIRCLE 14 ON INQUIRY CARD

MAGNETIC COMPUTER ELEMENT

200 Flip-Flops and 3000 Gates Packaged in One-tenth Cubic Foot.

A small rectangular bar of ferrite magnetic material measuring 50 x 50 x 85 mils makes possible reliable high speed computing at a reasonable cost. This entirely new magnetic computer element, called Biax, is capable of multi-megacycle performance in logical networks and memory arrays.

The basic concept employed is that of flux interference between orthogonal magnetic fields accomplished by means of two 20 mil orthogonal holes through the element. The flux interference takes place in the magnetic material between the holes. Because of the orthogonality, no normal magnet coupling occurs between conductors associated with the two holes in the materials. By controlling the spacing between the holes, the flux interference techniques can be made either destructive or non-destructive. Memory applications employ the non-destructive element whereas logical circuitry makes use of the destructive element.

In the memory element, one of the orthogonal holes acts as the storage axis while the other hole acts as the non-destructive interrogate axis. The Biax logical element employs the same orthogonal hole technique, with the exception that the holes are placed extremely close together.

Functioning as a memory element, Biax permits the realization of a very rapid random access memory unit. Elements have been interrogated over one hundred billion times at a ten megacycle rate with no loss in output signal, indicating true non-destructive readout and low heating. High speed operation up to 20 megacycles per second has been achieved. Operational memory circuitry and logical circuitry have been fabricated and operated at two megacycles thus it is possible to achieve computational equipment where the memory access time is properly matched with the logic processing speeds.

In addition to its ultra-high speed capabilities, the memory element permits operation under extreme environmental conditions. A memory array has been operated for eight hours at 125 degrees Centigrade. Extensive environmental tests indicate that arrays can be fabricated that will operate in the vicinity of the Curie temperature of the ferrite used in their manufacture.

Typical computer logical elements involve both gating elements and storage elements (flip-flops). Both types of logical elements have been successfully built and tested employing the Biax principle.

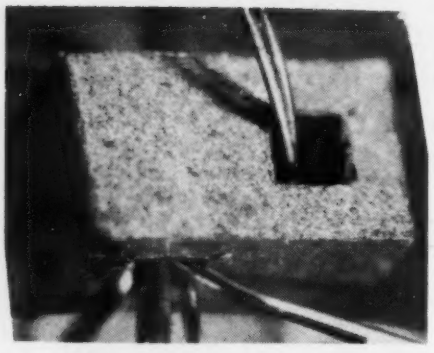


Fig. 1—This enlarged microscopic photograph of a Biax memory element shows details of wiring in the tiny, new computer component.

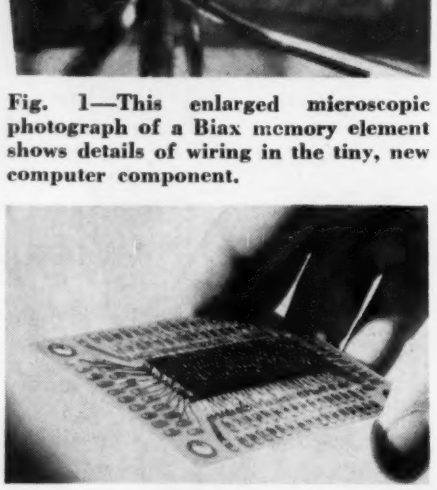


Fig. 2—A typical Biax array for an electronic digital computer memory unit, this printed card contains more than 300 elements. Multiples of such printed circuit cards are mounted adjacent to one another in a computer to provide large memory capability.

Fig. 3—Minuteness of Biax is shown in this photo of several hundred of the new computer elements with a nickel. More than 5,000 can be held in the palm of your hand, and 310,000 will fit in a quart milk carton. These elements are now in mass production, and complete Biax memory systems and computers are now being marketed for special commercial and military applications.

Because of their favorable environmental characteristics, Biax elements may be densely packed and thus permit achievement of extremely small volume, considerably smaller than is possible with semiconductor techniques. Two-hundred flip-flops and 3000 gates—the equivalent of 15,000 to 20,000 semiconductors—can be packaged in one-tenth of a cubic foot.

Application of Biax techniques will reduce the number of solder connections in a typical computer by a factor of 10 to 100, because many elements may be linked by a single wire, thus avoiding the large number of solder joints necessary when semiconductor devices are used. The number of connectors will also be reduced by a factor ten or more.

Because of the smaller currents required to operate the memory, the total power required to achieve a given computational speed is materially reduced.

The Biax concept and the associated digital computer components were invented by Cravens L. Wanlass, director of research for Aeronutronic's Computer Operations. Aeronutronic is now manufacturing Biax elements by mass production techniques. Biax techniques are currently being applied by Aeronutronic to a number of airborne and ground-based military projects where multi-megacycle data processing is required.

Circle No. 100 on Inquiry Card

Magnetic Digital Modules

Packard Bell Computer Corp. has developed magnetic digital modules that are compatible with their transistorized digital modules and can be mounted in the same self-powered case. These new modules are said to increase system reliability by reducing the number of active circuit elements and permit the operation of as many as fifty core stages from one drive transistor. System design time can be minimized as both core and solid state core driver modules are available. The magnetic modules can be incorporated in any digital system such as computers, automatic control systems, test equipment, telephone circuitry, switching circuitry and shift registers to achieve fewer components and easy replacement. Packard Bell Computer Corp., Los Angeles, Cal.

Circle No. 138 on Inquiry Card

Lightweight Accelerometer

New accelerometer, designed for applications where size and weight of the instrument are critical, ½ inch high and weighing only 9 grams provides 5 pk-mv/pk-g sensitivity with a first resonant frequency of 30KC. Frequency response ±5% is 2 to 6000 cps with amplitude linearity of 1% and temperature range of −70F to +230F. Endevco Corp., Pasadena, Cal.

Circle No. 229 on Inquiry Card

Vibration Mountings And Bases

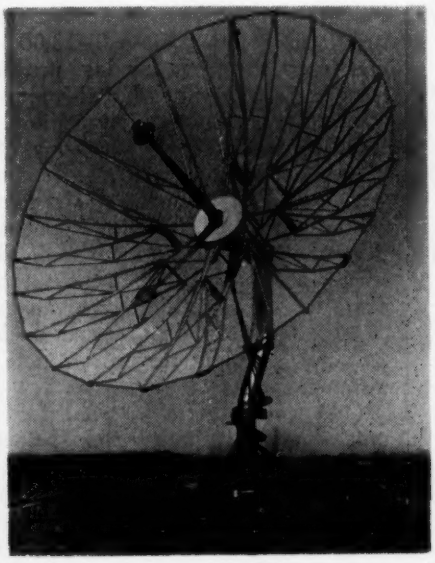
Designed and tested to conform to the requirements of MIL-C-172, mountings provide maximum vibration and shock protection for base-mounted avionic equipment at temperatures from −80 to 250F and frequencies from 5 to 500 cps. They incorporate amplitude sensitive damping which limits transmissibility at resonance to 3 without impairment of isolation efficiency at higher frequencies. Lord Mfg. Co., Erie, Pa.

Circle No. 142 on Inquiry Card

Magnetic Tape Tester

Used to check the quality of magnetic tape to enable tape manufacturers and users to guard against information loss due to defective coating, transistorized tester performs to automatically locate and indicate tape flaws that may be classified as noise or drop-out. Potter Instrument Co., Inc., Plainview, N. Y.

Circle No. 143 on Inquiry Card



Transportable Tracker

New tracking antenna has three important features: a folding 28-foot reflector, hand-operated elaz drive system and self-contained trailer mount and tower. The reflecting surface is a special reflective cloth which folds compactly, and the ribs of the reflector are hinged around the center section. When the reflector is collapsed into a compact bundle and the supporting pillar lowered onto the flat trailer bed the antenna is easily towed to another location. While the elevation and azimuth drives are intended to be operated by hand, motors and selsyns can easily be added if desired. D. S. Kennedy & Co., Cohasset, Mass.

Circle No. 215 on Inquiry Card

CIRCLE 16 ON INQUIRY CARD→

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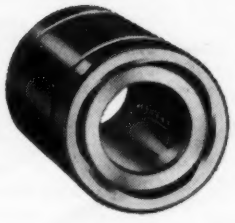

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PRESSURE STANDARD

Pressures From 0 to 10,000 psi Convert To Digital FM Signal

An unusual portable electronic secondary-pressure standard incorporates direct conversion of input pressures to a digital FM signal for rapid, accurate line, bench and process pressure checks. Replacing previous manometric and electro-manometric equipment, the Vibromanometer accommodates wide pressure ranges, and provides rapid response time and accurate operation from remote points. Readout of the unit, visual or printed, is adjustable for any desired measurement unit, such as psi, percent or full scale, millibars.

Engineers at BJ Electronics, Borg-Warner Corp. list many unique design features for the Vibromanometer, including the use of a proprietary Vibrotron Transducer which accepts pressure inputs ranging from 0—10,000 psi and converts these analog pressures directly to a precise digital-frequency (electrical) output. The Vibrotron Transducer operates by means of a vibrating wire anchored to a pressure-sensitive metal diaphragm. The vibrating frequency of the wire is inversely proportional to applied pressure. Electrical (FM) output of the Vibrotron Transducer is fed directly to an associated amplifier and processing-readout unit, with readout response said to be instantaneous.

Other advantages claimed for the unit over existing types of manometric or electronic pressure-standards include: elimination of normal electronic or mechanical errors, with no driving motors or gear trains required; elimination of complex electronics such as carrier and d-c amplifiers, voltage regulators, feedback correction elements and associated potentiometers and resistors; elimination of electronic converters since unit output is fed directly to the digital printer or recorder; ruggedness and relative freedom from maintenance compared with mercury standards which are essentially fragile and must be cleaned and checked frequently.

Circle No. 98 on Inquiry Card

Transistorized Inverter

Transistorized inverters provide 100% reliability with any d-c voltage up to 130 volts. Unit can convert directly from d-c to a-c without an input transformer, avoiding use of filter input or transient eliminator. Power Sources, Inc., Burlington, Mass.

Circle No. 163 on Inquiry Card

TO THE ENGINEER

who likes his switching gift-wrapped

If you want your control functions prewired, hermetically sealed in a neat package, tested out, and as ready as instant coffee, you're listening to the right people.

Because AE has a gift for wrapping up relays and stepping switches in tidy control packages of your design—or ours, if you prefer.

For instance, the control package illustrated houses an AE Type 45 Rotary Stepping Switch wired to multiple-pin headers for direct plug-in (and we supply the properly oriented socket mounting plate). This particular job has 462 connections, and could just as readily be equipped with MS connectors for insertion in matching cable plugs.

The point is, we've been wiring telephone switchboards and automatic control devices for years, and have the technique down pat. So pat that it would probably cost you less to let *us* do the job.

Besides, AE engineers are past masters at designing complex switching circuits. You can leave it to them, if you wish, to dope out the least expensive way of accomplishing the most sophisticated switching.

How about letting us in on *your* control problem? Just write the Director, Control Equipment Sales, Automatic Electric, Northlake, Illinois. Also ask for Catalog 4083: "Hermetically Sealed Relays and Switches."

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- Small size
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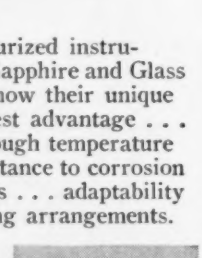

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CIRCLE 19 ON INQUIRY CARD

CONTINUOUS READING METER-RELAYS

Assembly Products' meter-relay, of the locking contact type, allows indicating pointer to pass the contact set point. V-shaped toggle, with contacts on each of its arms pivots on the under side of the adjustable pointer that marks the set point. Both the toggle and the adjustable pointer are made of layers of isolated metal that are parts of separate circuits from the respective toggle contacts. When the indicating, or signal, pointer reaches set point, a two-stage action occurs, a'most instantaneously. A contact on the pointer touches a contact on the toggle and a circuit is closed through both the booster coil and the coil of a multi-pole load relay. As the load relay initiates the desired control action through one set of contacts, another set closes and pu'ls a surge of current through the meter-relay movement. Enough torque is thus added to the indicating pointer to cause it to snap the toggle and move past it. The meter-relay contacts are then separated and the booster circuit is opened. This sequence of action may begin at either high or low limit. The load relay remains energized as long as the signal is higher (or lower) than set point. The indicating pointer moves freely with fluctuating signal strength. When the indicating pointer returns to set point, its contact again touches a contact on the toggle. A circuit including the booster coil is closed and the load relay is dropped out. The indicating pointer snaps the toggle the other way and again pushes past, opening the booster circuit once more.

Pointer Trips V-Shaped Toggle Switch

Normally when a meter-relay of the locking contact type reaches contact point, it can't be read. A sampling signal involving a number of auxiliary control components such as interruptors, condensors and resistors generally must be used to read above the contact point.

Assembly Products, Inc. has solved this problem with a new locking contact meter-relay design which may be used in any application requiring only one set point. See diagram for operational functions.

With the new (continuous reading) design, the moving pointer shows the signal level at all times, even when the set point has been passed and control circuits have been energized. The circuits remain operative until reset calls for opposite action.

As in present meter-relays made by Assembly Products, a separate coil increases control dependability by boosting contact torque at set point and thus insuring positive actuation of a load relay.

Sensitivities are the same as those of existing API meter-relays, beginning with full scale ranges of 0 to 5 microamperes. Any of the present meter styles may be specified.

Key to the new design is a v-shaped toggle, with contacts on each of its arms. The design and positioning of the toggle are such that a contact on the indicating pointer always passes by the toggle arm closer to it and strikes the contact on the further arm. The indicating pointer has two isolated contacts, one touching a toggle contact while moving upscale, the other being operative when the pointer moves downscale.

Movement of pointer contacts across the toggle contacts exerts a wiping action that keeps contacts clean and makes for more positive action and longer contact life.

Circle No. 88 on Inquiry Card

Silver-Zinc Batteries

A new line of silver-zinc secondary (rechargeable) batteries for missiles and spacecraft have extremely high energy-to-weight ratios compared to ordinary batteries. They are made up of individual cells combined to develop the power required. The silver-zinc cells range in size and output from the Type SC-04 miniature cell of 0.5 ampere-hour capacity which weighs only 0.05 pound and has an output of up to 10 amperes, to the Type SC-450, a single cell with a weight of 9.7 pounds and an output of 450 ampere-hours. All cells are rated with a terminal voltage of 1.4 volts under load.

A unique plate and separator construction withstands heavy overloading with little heating and gassing. The dry-charged shelf life of the batteries is a minimum of 5 years. Cook Batteries, Denver, Colorado.

Circle No. 251 on Inquiry Card

10,000-Volt Silicon Rectifiers

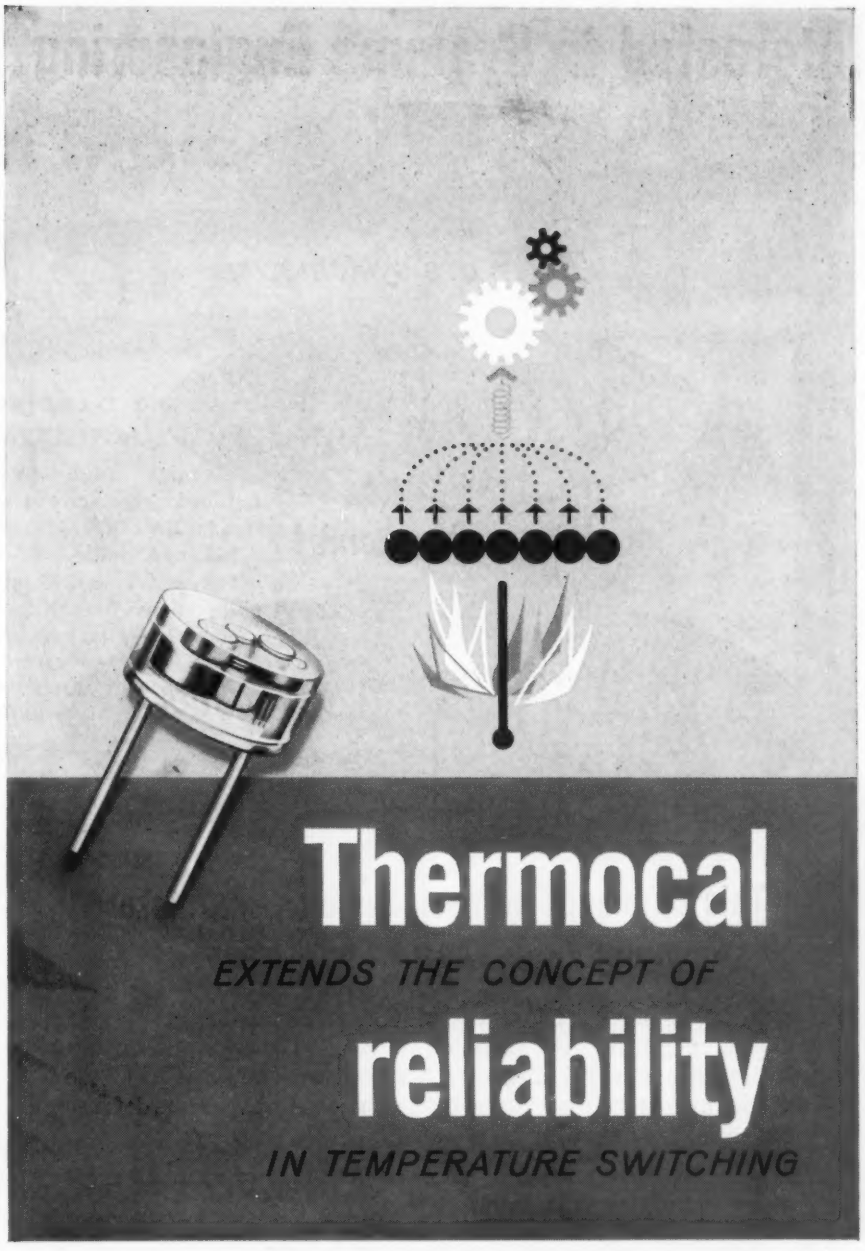
Four new high voltage, high current silicon rectifiers are said to provide higher current ratings, lower forward voltage drop and better reverse leakage characteristics than previously available types. Designated IN2382 thru IN2385, the new units are rated at 4000, 6000, 8000 and 10,000v PIV and maximum rectified current at 25C of 150, 100, 70 and 70 mA, respectively. The nonmetallic case with a dielectric strength of 400 volts/mil and resistivity of more than 10^{14} ohm-cm, is electrically "cold", allowing simplified mounting methods. The 4000v units are one inch long, the 6000 and 8000v units 1½" long and the 10,000v unit 2" long. All of the new types are ½" in diameter. Axial leads are 0.030" diameter by 1¼" long. Pacific Semiconductors, Inc. Culver City, Cal.

Circle No. 218 on Inquiry Card

Explosion-Proof Differential Pressure-Vacuum Control

Five models of a new differential control have been designed for use in areas where explosive gases or vapors are present, and where it is necessary to know the difference between two separate pressures or vacuums. Several system differentials are available between limits of 30" hg. and 40 PSI, with switch differentials from .5± 1/10" hg. and up. Switches are single pole and suitable for ambient temperatures up to 100F and are rated 15 or 20 amp., 115/230 Volts AC. United Electric Controls Co., Watertown, Mass.

Circle No. 233 on Inquiry Card



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CURRENT RANGE: 10 to 500 Amperes
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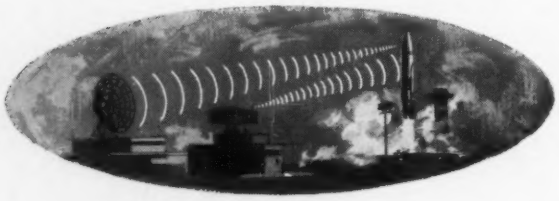

...and systems

...and TOTAL systems in which the big bird and support equipment may rank only as a component.

This difference between systems can make a big difference in your career

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COMPONENTS DESIGN

Ultra-Low Noise Choppers

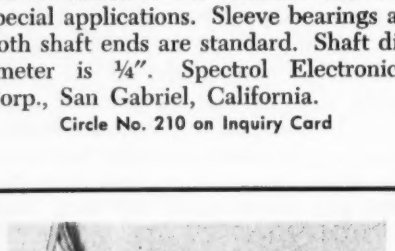
Eight models of a newly developed ultra-low noise chopper have single-pole double-throw and double-pole double-throw types in both make-before-break and break-before make models, 60 or 400 cps. Internal shielding, plus mumetal containers make the ultra-low noise level possible. A unique chopper structure, meeting MIL specs-results in extra stability over a wide range of drive voltage, excitation frequency and operating temperature. Collins Electronics Manufacturing Company, Stevensville, Md.

Circle No. 238 on Inquiry Card

7/8 Inch Ten Turn Pot

⅞ inch low-cost ten-turn precision wirewound potentiometer is now available in ranges from 25 to 120 K ohms. Standard linearity tolerance is ±0.25% with tolerances of ±0.1% on special order. The Model 510 will operate over a temperature range of −55C to +105C. Up to 46 additional terminals can be added to the standard unit for special applications. Sleeve bearings at both shaft ends are standard. Shaft diameter is ¼". Spectrol Electronics Corp., San Gabriel, California.

Circle No. 210 on Inquiry Card



Hermetically Sealed Stabilization Cavity

New series of hermetically sealed, light weight stabilization cavities from Varian Associates has the following specs. Frequency: fixed tuned (with ±15 Mc trim) at any frequency from 8500 to 9600 Mc. Stabilization factor: 20 (with VA-201 B klystron). Insertion loss: 10db, Unloaded Q: 20,000 temperature.

Circle No. 171 on Inquiry Card

Miniature Choppers

Miniature rugged choppers have contact rating from dry circuit to 100 volts, and thermal drift of less than one microvolt. Temperature extremes (−65° to 125°C) have negligible effect on phase angle. The Bristol Company, Waterbury, Conn.

Circle No. 223 on Inquiry Card

High Impedance Size 8 Control Transformer

New 400 cycle high impedance control transformer, CTC-8-A-6, has impedance levels comparable to those found in size 10 and 11 synchros. Maximum error is 7′ of arc. Unit is standard 11.8 volt input control transformer. Power input is as low as 0.058 watts. Complete electrical characteristics and outline drawings available. Clifton Precision Products Co., Inc., Upper Darby, Pa.

Circle No. 190 on Inquiry Card

Spring-Loaded Contact Plug

Spring-loaded probe or plug provides positive through-connection from practically zero to a maximum of 2.5 oz. necessary for its full travel of .187″. Contact probe is of the plunger-type construction and is activated by pressure applied axially. The terminal incorporates the well-known "Press-Fit" features of simple one-piece installation in a drilled or punched hole in the metal chassis or support, with marked space saving, so that a plurality of such contacts can be mounted close together. Terminal is adaptable to applications calling for a spring-loaded, rather than a rigid probe. Sealectro Corp., Mamaroneck, N. Y.

Circle No. 170 on Inquiry Card

Miniature Servo Motor

A size 5 servo motor weighing only 0.6 oz., yet delivering 0.10 oz-in of stall torque has been designed to meet the severe environmental and physical requirements of air and missile borne guidance systems. Power requirements are 1.5 watts per phase at 26 volts, 400 cps. Under these conditions, the units accelerate at 39,000 radians/second/second until the free speed of 10,000 is reached. Moment of inertia is .18 g-cm². Daystrom Transicoil, Worcester, Montgomery County, Pa.

Circle No. 231 on Inquiry Card

New Designs in Motors from HOLTZER-CABOT

VARIABLE SPEED SUB-FRACTIONAL DC MOTOR

This new motor—Model RBD-25—is available in two standard units: RBD-2505 with a rating of 0.5 oz. inches; and RBD-2510, rating 01.0 oz. inches. Both operate at speeds up to 1800 RPM with input of 24 to 115 V. D. C. This is a shunt wound motor and speed can be varied by changing armature voltage.

2-SPEED REVERSIBLE SUB-FRACTIONAL AC MOTOR

Model RBC-2514. Available with basic speeds of 1800 RPM and 3600 RPM and with standard gear reductions from 3:1 to 3600:1. Basic torque ratings for continuous duty at 115 volts, 60-cycles; 3600 RPM synchronous range from 0.15 to 0.5 oz. inches.

SYSTEMS DEVELOPMENT MOTOR KIT

Designed primarily for research laboratories and engineering departments, this kit makes it possible to determine the proper servo, torque or synchronous motor required for instrumentation and automation applications. Eliminates the need for purchasing sample motors for testing. Contains all the necessary motors and components to assemble—with bench tools only—32 different motors.

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Load — 32 oz-in.
Backlash less than 0° 1.5′.
Breakaway torque at zero load: 0.05 oz-in.
End gears interchangeable; supplied in 48, 64, 96 or 120 pitch.
Stainless steel throughout.
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Stocked in 1/8" and 3/16" bores.

Dependably precise mechanical differentials for use in high-accuracy electro-mechanical computer assemblies. Every detail of construction in compliance with the most rigid specifications. Available in MINIATURE sizes in single- and double-pinion hollow-shaft design with removable end gears. Compact, easily installed in tight space; light in weight yet rugged.

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Equally high relative precision will be found in this larger series of Reeves Differentials.

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CIRCLE 24 ON INQUIRY CARD

PERMANENT-MAGNET D.C. MOTORS

- 7/8 IN. IN DIAM.
- 2½ OUNCES
- 4-30 VDC
- TO 20,000 RPM
- SELF-SHIELDING

All-new PM-1 line for hard-to-fit applications. Compact motors feature ceramic field structure, efficiencies from 40-50% — give equivalent output power with ⅓ less bulk than older design.

Available governed or ungoverned with choice of bearings, shaft extensions and mounting arrangements; gear motors with various speed reductions. Vibration- and shock-resistant. Special modifications invited.

Write for complete specifications.

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CIRCLE 25 ON INQUIRY CARD

DEVELOPMENT AND UTILIZATION OF REDUNDANT SYSTEMS

S. Nozick
Hughes Aircraft Company
Tucson, Arizona

In designing extremely reliable systems, the engineer finds himself limited, for as he makes the system more complex, the increased number of parts causes more frequent failure or unreliability. The reason for this is that most systems are built in such a way that any single part failure disables the entire system.

The usual engineering approach to this problem is to use more dependable parts or those with low failure rates, and, combine this with extremely careful design. This approach can, and does, reduce the system failure rate. The limit of what can be achieved this way is in the quality of the parts. Therefore, for complex systems, the problem of achieving extreme reliability is very real and often, currently, an impossible one.

Here we describe a technique of developing redundant systems whose reliability is not limited by the danger that any single part failure can disable the entire system. Such a system is tolerant of part failure.

REDUNDANCE

Redundance is a technique of constructing systems with spare parts built into the system. In a redundant system, part failure does not mean complete system failure since the spare parts keep the whole system operating. This technique makes it possible to build very complex systems with conventional parts and still have a low in-use failure rate. In-use failure rate of redundant systems can be thousands of times lower than conventional systems, making redundant system desirable in uses where low in-use failure rates are essential. Examples of such cases might be a supersonic aircraft auto-pilot or a nuclear warhead fuze.

LIMITATIONS

Redundant systems solve some of the reliability problems,

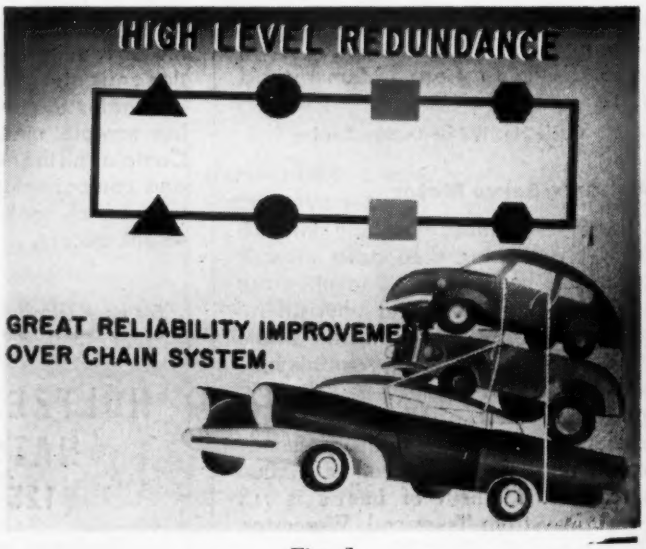

Fig. 1

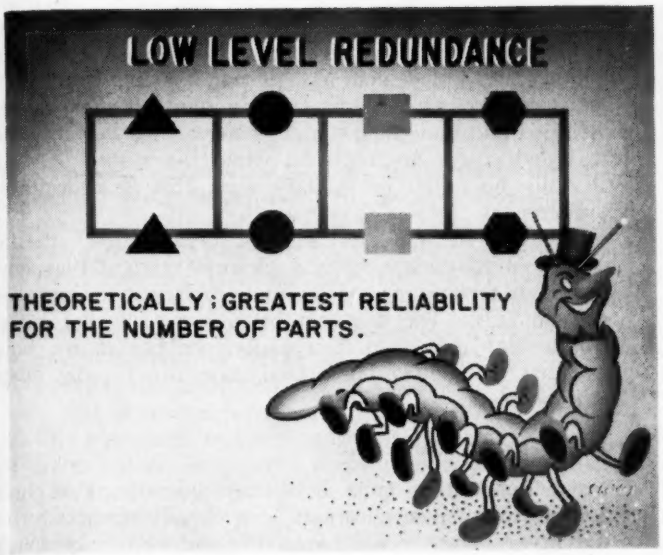

Fig. 2

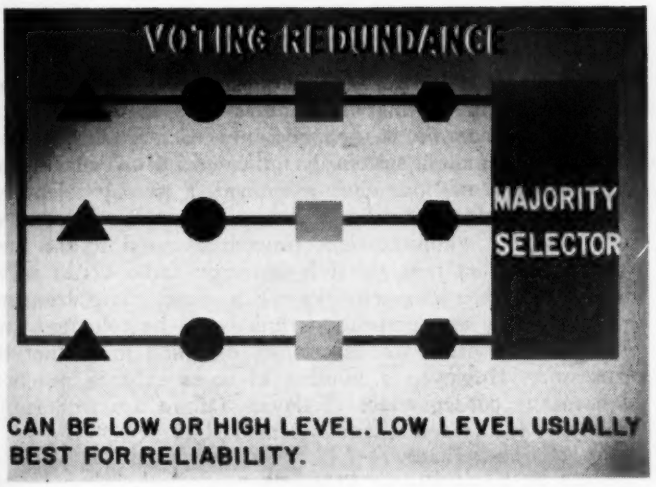

Fig. 3

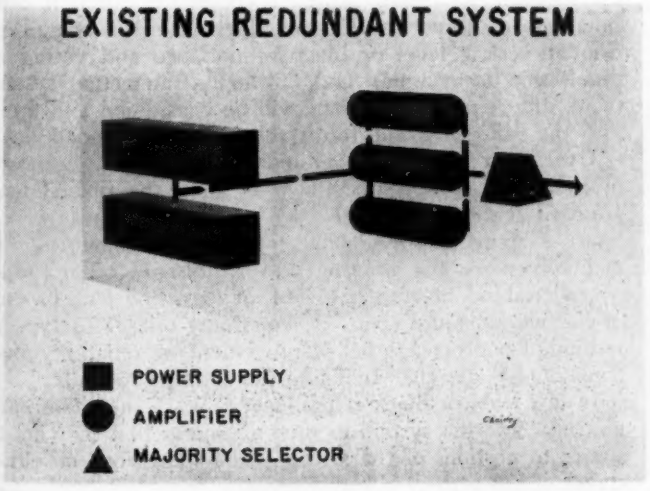

Fig. 4

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DPDT
chopper
C1430 Series

- Excellent tracking
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- Phase stability with temperature
- High vibration rating
- High contact rating
- Long life • Reliability
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Also available in . . .
- 2 Hole flange
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actual size

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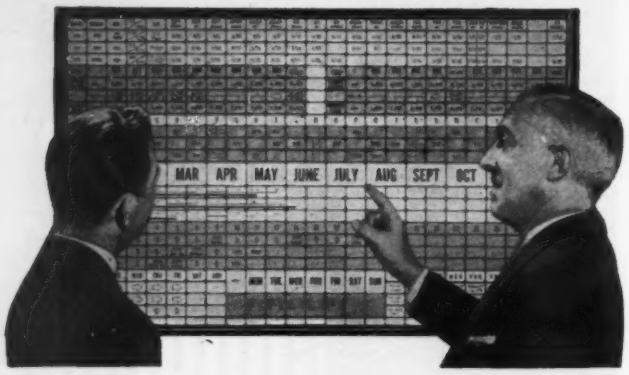
How To Get Things Done



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but do have their limitations. Even though they give a tremendous reduction of the in-use failure rate, other system qualities are changed. The redundant systems are heavier and larger than the current ones because of the built-in spare parts. They are more inherently costly because of the size. In use, these systems have an increased part replacement rate. However, this increased part replacement rate is not a major problem to the user. Part replacement in redundant systems can be scheduled and done at the user's convenience because only the failed spares are replaced while the system itself is still fully operable. In military uses, this is a desirable characteristic.

The research and development organization entering the area of redundant systems requires reorientation since the design techniques for building such systems are limited and new. The engineer often has to invent rather than develop or design. Our experience has shown however, that an engineering organization can rapidly adapt to the problems.

FUNCTIONAL REDUNDANCE

Since redundant systems have characteristics that limit their use in some applications, you should examine other alternatives before deciding on the redundant approach. One alternative, functional redundance, is duplication of the device's function elsewhere. If the function of the proposed device could be wholly or partially performed by other devices, it may not be necessary to build for a high enough degree of reliability to require redundance.

For example, if we were considering building a communications link for combat military use, it might at first seem that extreme in-use reliability is required and an internal redundant system is indicated. However, if the field usage conditions were examined, a nearby telephone or radio might be found to be present under all tactical conditions. Communications procedures used might then be modified so that the telephone or radio could serve as an alternate channel. With this done, more frequent failure of the communications link could be tolerated and redundance within the link being designed might not be necessary. However, a number of cases exist in practice where the consequences of device failure are sufficiently costly to justify redundant system design.

TYPES OF REDUNDANT SYSTEMS

Redundant systems can be built with many configurations. All redundant systems however consist of different combinations of three basic forms, high level or overall redundance, low level or block redundance and voting redundance. In planning and developing an actual system, many different configurations will be considered and therefore the different basic forms should be understood.

Overall or high level redundance is the simplest way of including spare parts. Two or more parallel systems are used as shown in Fig. 1.
Spare systems can be connected either automatically or manually when the working system fails. In order for an overall redundant system to fail, at least one part in each of the working and spare systems must fail. This type of redundance gives a great improvement in reliability over conventional designs. It is also the simplest to build.

In low level or block redundance, Fig. 2, the spare parts are built into the system in such a manner that they act as spares to portions of the system. The spares can be either stages of the system or components.

For a low level redundant system to fail, at least all

the working blocks and spares of one type must fail. For the same number of parts, this type of system gives a greater reliability than overall redundance which can be seen by comparing Figs. 1 and 2. If two dissimilar blocks, one in the upper chain and the other in the lower one failed, the high level redundant system in Fig. 1 would be disabled. However, if the same failure occurred in the low level redundant system, Fig. 2, no system failure would take place. Each of the dissimilar blocks has its direct spare in Fig. 2, but not in Fig. 1. Following this line of reasoning, we can conclude that the lower level in the system that blocks are paralleled, the greater the system reliability. The goal of the designer should therefore be to parallel parts rather than sub-systems or stages.

Voting redundance, the third basic redundant configuration, is shown in Fig. 3. It consists of three (or in general "n" subsystems with a majority selector. The majority selector compares the outputs of the subsystems and selects those subsystem outputs that agree. For example, in the illustrated case, the majority selector would select the outputs of the two subsystems that are identical and use this as the redundant system output.

This structure is particularly useful in cases where failure of a subsystem can occur in a large number of ways—noise, microphonic, low signal output, no output, excessive output, oscillation, etc. Failure of such a configuration occurs when the majority of the subsystems fail, or when two failures occur out of the three subsystems, or when the majority selector fails.

Since the majority selector is a series element in the system, it's complexity is the limiting factor in this configuration's reliability. This configuration gives a marked reliability increase over conventional systems but not as great an increase as either low level or overall redundance. However, with the current state of the art, this configuration can often be quite easily built.

All actual composite redundant systems are a combination of these basic configurations. Fig. 4 shows a system that consists of both voting and block redundance.

METHODS OF CALCULATING REDUNDANT SYSTEM RELIABILITY

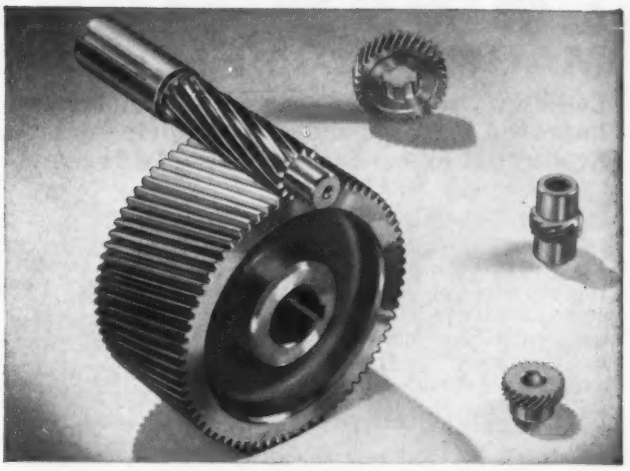
SYSTEM TYPES	RELIABILITY
• CONVENTIONAL	$e^{-t/m}$
• REDUNDANT COMBINATIONS ONE OUT OF TWO	$2e^{-t/m}-2e^{-2t/m}$
ONE OUT OF THREE	$3e^{-t/m}-3e^{-2t/m}+e^{-3t/m}$
• VOTING REDUNDANCE	$3e^{-2t/m}-2e^{-3t/m}$

Fig 5

ESTIMATING RELIABILITY OF REDUNDANT SYSTEMS

In estimating reliability factors of redundant systems, two items need to be considered: the in-use system failure rate and the block replacement rate. In-use system failure rate is the same as the redundant system probability of failure. Block replacement rate in a redundant system is distinct from the failure probability and should be estimated separately for the system planned.

Redundant system failure probability is obtained from the block mean-time-to-failure and the redundant configuration used. Individual block mean-time-to-failure, m, or its reciprocal, failure rate can be estimated by the technique shown in the Reference. The individual configuration reliability which is defined there as the probability of not failing, R, can be then calculated as shown in Fig. 5 in terms of the block mean-time-to-failure, m, and the period of untested use, t. Redundant system re-



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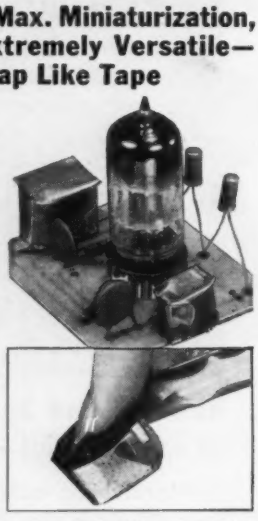

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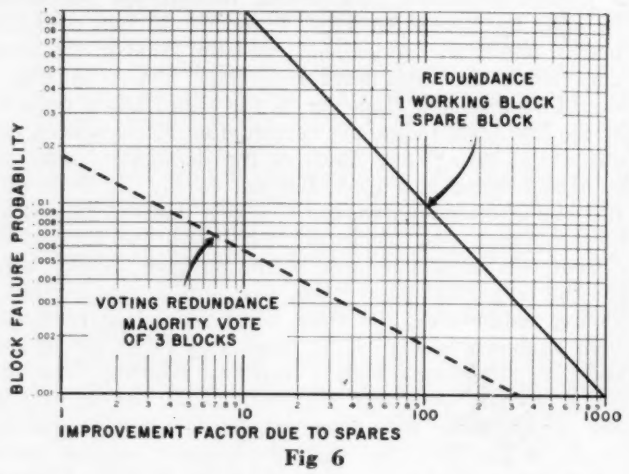


Fig 6

liability, again defined as the probability of not failing for time t, is the product of all the series individual configurations' reliabilities. System in-use failure rate or probability of failure is the difference between unity and the product of the series configurations' reliabilities. The redundant system block replacement is estimated simply by taking the sum of all the individual block replacement rates (the sum of the reciprocals of mean-time-to-failure).

IMPROVEMENT OBTAINED BY REDUNDANCE

A measure of the improvement in reliability obtained by redundance is the ratio of the probability of failure of a conventionally designed block, or system, to that of the redundant block or system. Figs. 6 and 7 show this calculated by the forementioned techniques for the three basic configurations. Fig. 8 shows a calculated chart for several assumed systems capable of performing the same type of functions. This chart is calculated from Figs. 5, 6 and 7 and shows the tremendous improvements theoretically possible.

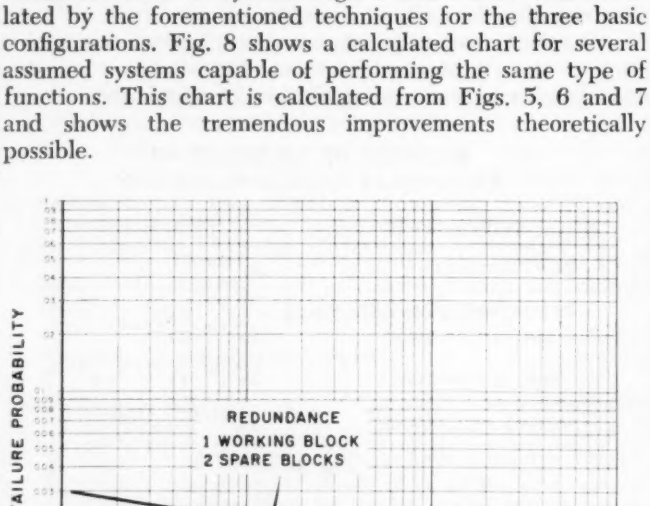


Fig 7

Switching may be required practically in a real system. Though this can reduce the improvement factors shown in Fig. 8, a marked improvement in failure probability, better than that possible with conventional reliable design, is obtainable.

FAILURE INTERACTIONS

In attempting to parallel blocks of a system, the effects of different types of block failure have to be considered by the designer and system planner. If this is not done, it is

perfectly possible to decrease reliability by paralleling blocks.

Even though we usually think of blocks of a system as either operating well or having failed, the different modes of failure are rarely considered fully or their frequency tabulated. For example, if we consider a tube, it can fail in many ways, inter-electrode shorts, filament either open or shorted, microphonics, noisy operation, excessive leakage between elements, gassiness etc. If we consider the effect of any one of these malfunctions on two tubes in parallel, it is apparent that some malfunctions in one tube would cause failure of the combination. Which malfunctions can cause this is a function of what the two parallel tubes are required to do in the system. The same can be said of any other component and also of any stage or subsection of the system.

POSSIBLE SYSTEM IMPROVEMENT

		1000 BLOCK SYSTEM EACH BLOCK HAS FAIL. PROB = 10^{-4} or $\frac{1}{10,000}$		
	DEG.	RELIAB.	SYS. PROB. FAIL.	IMPROVE.
CHAIN SYSTEM	—	.9	.1	1
OVERALL REDUNDANCE	2	.99	.01	10
	3	.999	.001	100
	4	.999,9	.000,1	1,000
BLOCK BY BLOCK REDUNDANCE	2	.999,99	.000,01	10,000
	3	Apx. 1	.000,000,001	100 Million
VOTING REDUNDANCE — Overall	2/3	.969	.031	3
VOTING REDUNDANCE — Block	2/3	.999,97	.000,03	3,333

Fig 8

The question that arises naturally is whether the combination of parallel blocks are more or less reliable than the single block. Based on experience, this question can rarely be answered. It requires a knowledge of the relative frequency of different types of failure of components in different environments and applications. Little data of this sort exists.

This lack of information does not prevent the development of redundant systems. An overly conservative design philosophy requires the redundant system to have the characteristic that no single component malfunction of any type be capable of disabling the system.

While this philosophy does not result in the optimum redundant system (max reliability per pound) it does circumvent the problem of a limited state of knowledge about part behavior in the field today. As more becomes known in this field by design experience, redundant systems that are more nearly optimum will be built.

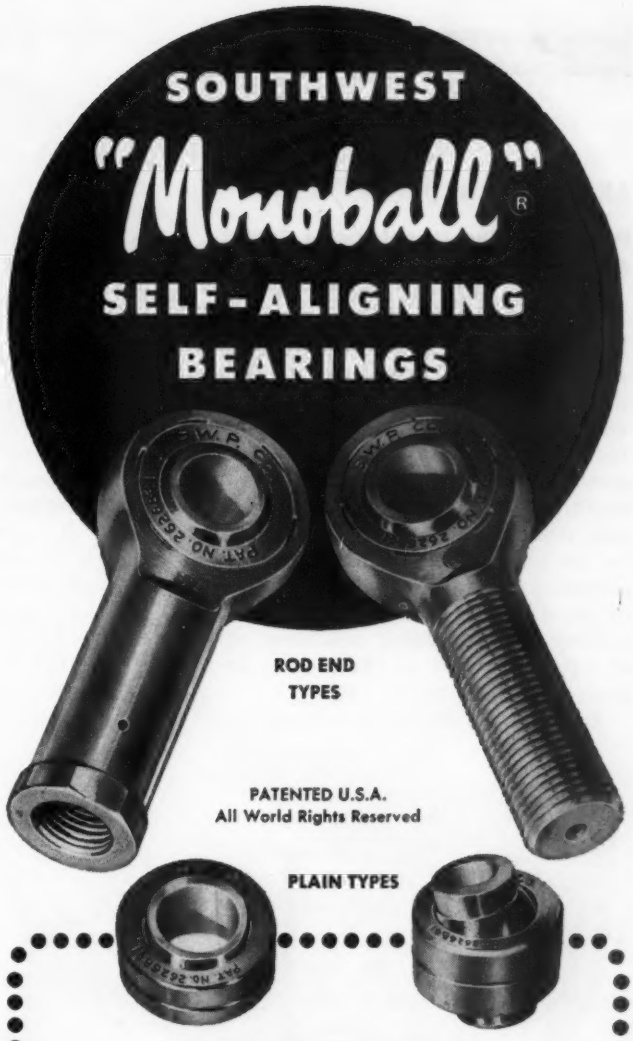
PARALLEL INTERACTION

When devices are placed in parallel, their operation and tolerance requirements change. For example, consider three alarm clocks on your dresser. If they were all set to go off at six o'clock in the morning, the fastest one would tend to awaken you too early. However, if they were interconnected so that the earliest two out of three awakened you, it might not be too early to be obnoxious.

Obviously if only say three minutes too early were tolerable, the alarm clocks in the voting or majority case can be less accurate than in the other case and also less accurate than a single alarm clock. In redundant systems, the special tolerance requirements have to be considered along with the construction and planning. For this, a statistical background should be present in the group.

Editor's Note: Mr. Nozick presented this material at the 1959 IRE Convention. In this paper he also discussed the manpower organization required to achieve the objective he set forth.

For more information on this aspect of the topic write directly to:
S. Nozick, Hughes Aircraft Co.,
P. O. Box 11337, Emery Park Station, Tucson, Arizona



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Up until Keuffel and Esser Engineers attacked the problem, encapsulated liquid in the conventional bubble level vial and the pendulum have been virtually the only way of detecting the direction of gravity. Unfortunately the sensitivity of level vials at best is only one second of arc—and then it must be visually observed. Such visual observation normally precludes the use of level vials for automatically controlling and recording positional tilts of structures such as radar axles and launching platforms.

By adding a mirror to a suspended pendulum K & E engineers have designed an instrument that represents a step forward in gravity sensing equipment. The device consists primarily of two units: a sensing unit and an indicating unit. The sensing unit reads the angle of tilt against true horizon in one plane displaying the output on a calibrated dial; an electrical signal, is available for recording instruments, remote control or for driving cerval units.

K & E engineers selected a photoelectric method for angle measurement because it utilizes the advantages of the high stability and high magnification available in optics in conjunction with the convenience of electronic readout. High magnification results from the fact that a reflected beam is deviated by twice the angular displacement of a mirror, inherently containing twice as sensitive a measurement method as any other available. High stability results from the application of the null principle—similar to comparing the weight of two blocks on a balance rather than weighing each block separately and then comparing the results.

In the photo detection of an angle K & E engineers considered three methods: the interferometer method, the phase shift method and the intensity comparison method.

In the interferometer method, light waves, reflected back and forth between two mirrors, interfere with each other causing fringes to appear. Commonly called Newton Rings, each fringe for a given mirror diameter corresponds to a certain angular value. Counting the fringes permits the angle to be determined. Since the measuring of the wave length of light is a well established procedure this method is probably one of the most accurate standards available to engineers and can be considered a primary method of measurement when applied to angles. Unfortunately, the interferometer is still an extremely delicate laboratory instrument, not easy to handle. In addition the electronics involved in counting numerous fringes puts the cost of an instrument in the $20,000 range.

The phase shift method is based on comparing the phase shift of two waves generated by the same light source but out of phase originally by 180 degrees. One wave is directed at a photocell and the other at a target. The mechanical arrangement is such that phase changes from the original 180 degree phasing is a measure of target shift or angle of tilt. Its advantage is that the method requires only one photocell and thus is insensitive to changes in photo cell sensitivities. Its major disadvantages are that it requires large lens appertures and high grade optical elements to obtain the necessary sensitivity and resolution, and large angle measurements cannot be made because of inherent ambiguities at the larger shifts.

K & E engineers finally decided on the intensity comparison method—splitting the image of a target into 2 equal halves. Comparing the intensity of each half with a photoelectric null device gives the zero position; deviations are indicated by the amount by which the bridge circuit is out of balance. Disadvantage of the intensity comparison method is that it does require two photo cells that have to be matched and that should not change properties during measurements. Its advantage is that the instrument has no moving parts, and is basically a simple design independent of the resolving power which in general limits optical sensitivity.

Optical system in the sensing unit is housed in a heavy bronze casting with three precision ground legs that act as the reference plane. Sensing element is the pedulum mirror whose relative position is determined by the two photo cells. Drift of the instrument at constant ambient temperature per twenty-four hours is one half of 1% of the range, primarily due to the aging of the photo cells. Drift tests were made by locking in the pendulam, effectively isolating the drift of the photoelectronic circuitry from the pendulum position against gravity. Sensing units cover a scale range of ±25 seconds of arc to ±15 minutes of arc. Same principles were applied to the design of an electronic autocollimator except that the mirror is no longer pendulam suspended, basically the only change in the optics. Autocollimator (top) and tilt angle transducer (bottom) use the same indicating units and power amplifier. Analog output from the unit for a shock recorder or servo system is a linear d-c voltage with a maximum sensitivity of 0.4 volts per second of arc. Maximum linear range is ± 10 volts or ± 15 minutes of arc, whichever limit is reached first. Sensitivity and range can be set to satisfy the particular requirements within the range as indicated. Sensing unit output is converted in the indicator unit to read a calibrated dial; indicator unit has a cathode follower output with an output impedance of 2,000 oms; amplification factor is 0.9.

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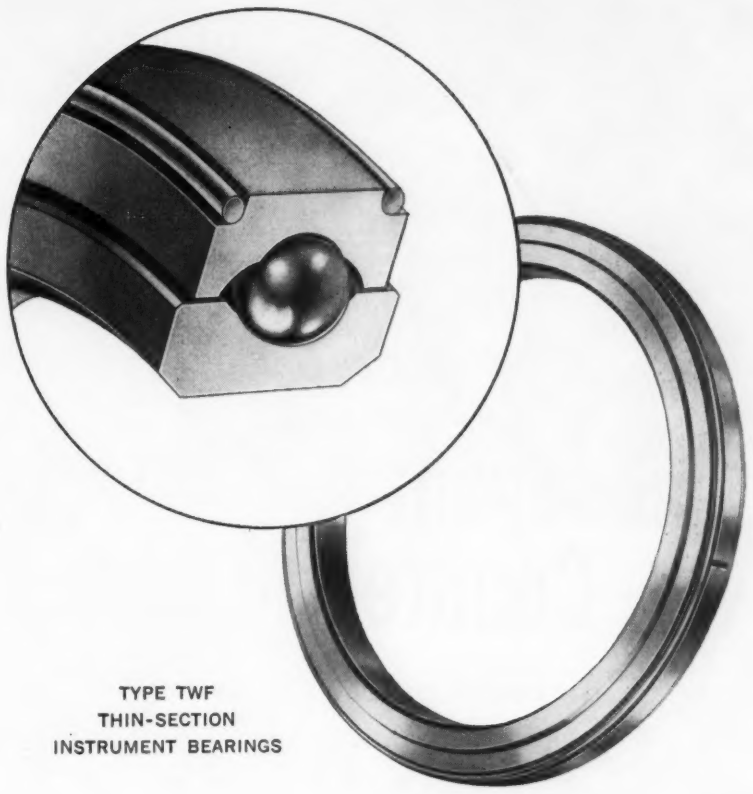

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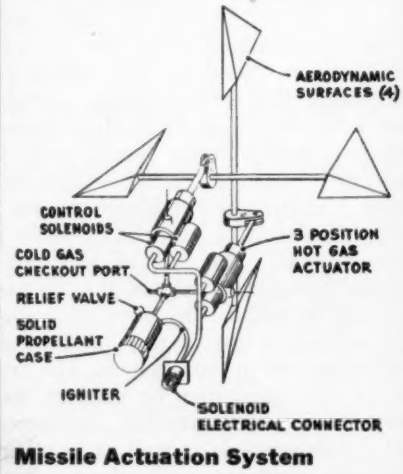

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Circle No. 137 on Inquiry Card

Scientist at the Avco Research and Advanced Development Division in Wilmington uses an ultrasonic pulse system to measure the temperature of the new p'asma jet developed by Avco. The quartz probes extend into the plasma flame and transmit and receive sound pulses which are converted to temperature measurements. The small plasma generator has been measured above temperatures of 12,000F.

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Using the Avco plasma generator, techniques may be developed to flame-spray refractory oxides and ceramics onto other materials to greatly increase their refractory properties. The unit can be fired into a vacuum or pressure chamber without major modification.

In flame spraying, the material is fed as a powder into the flame, becomes liquid and is hurtled in fine, spherical droplets against the surface to be plated. Initial ceramic spraying experiments have shown that a slightly porous coating is deposited which improves the specimen's surface thermal insulating properties and resistance to thermal shock. Avco has also used the plasma jet, as it is sometimes called, for materials testing and spectroscopic studies.

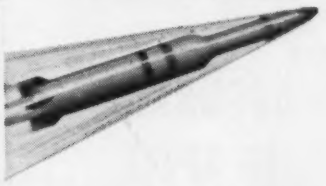
The unit is especially suited to low cost operation because no special facilities or services are required. It operates from a standard welding generator, using a commercial bottled gas such as argon, nitrogen or helium and tap water for cooling. At a power level of 5 kilowatts it may be operated for an almost unlimited period.

Basically the unit is a high intensity electric-arc consisting of a water cooled tungsten cathode designed to reduce contamination to insignificance, and a copper anode. It is 2¼ x 9 inches long and weighs 3½ pounds. The jet can be varied by changing nozzles which are available in 0.25 to 0.50 inch inside diameter. Standard nozzle size is 0.375 inch inside diameter. The unit can also be equipped with a pistol grip handle to develop techniques for arc plasma flame cutting and other applications.

The new arc is part of a family of plasma generators being developed for industrial and laboratory use by the Research and Development Division of Avco. Avco's larger plasma generator can also be adapted for use in arc-heated wind tunnels or for closely simulating environmental conditions of air enthalpy, pressure and heat flux associated with hypersonic re-entry of ballistic missiles. Temperatures obtained with the larger generators have reached 18,000F.

Circle No. 83 on Inquiry Card

ELECTRONICS: Over, on and under...



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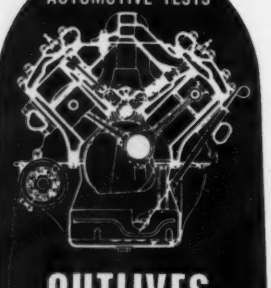

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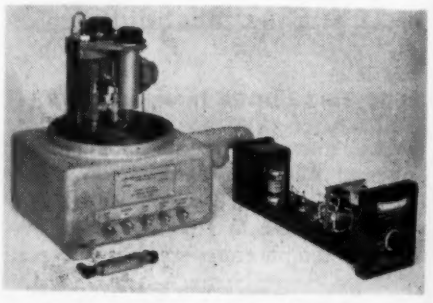
NEW TECHNIQUES

MOISTURE MONITOR

Cell Electrolyzes Moisture Present In Stripping Gas

An electrolytic cell employing a coulemetric principle delivers accurate, rapid analysis of moisture in trace or percentage quantities. Consolidated Electrodynamics' new monitoring instrument gives a continuous read-out of the quantity of moisture in liquids. Quantities as small as one part per million can be detected.

To adapt the electrolytic principle for use with liquids, CEC introduced a stripping column ahead of the electrolytic cell to remove all moisture from the liquid sample. The liquid trickles down an internally threaded groove in the column. As stripping gas passes from bottom to top through the center of the column, it pulls the moisture with it. Internal construction assures that the gas and liquid are brought into intimate contact and that foreign gases or moisture are not introduced. The stripping gas then passes into the electrolytic cell for analysis of the amount of moisture it has accumulated.



Besides making moisture detection and control quicker and more accurate, the continuous monitor will be useful in automation for controlling moisture content in liquids. This advancement is not possibe with conventional wet-chemical procedures which have the disadvantage of being dependent on human operations in sample taking, instrument reading and adjustment. The new moisture monitor can signal the opening or closing of valves to maintain a precise addition or rejection of moisture. Because of its rapid response characteristics, the instrument will eliminate much complex controller mechanism and installation engineering time.

The cell consists of a small diameter tube that houses a pair of platinum wires wound in a double helix on its inner surface. A partially hydrated phosphorous oxide film coats the wires and the space between. Resulting cur-

rent flow is directly related to the mass flow rate of moisture through the cell by Faraday's law, which states that 2 x 96,500 or 193,000 coulombs are required to electrolyze one molecule of water. Therefore the current is proportional to the mass flow rate of moisture through the cell. Because the total mass flow rate of liquid sample into the instrument is held constant by a metering pump, and moisture in this liquid is quantitatively removed in the stripping column, the current generated by the cell is proportional only to the moisture content of the liquid sample.

An inert dry gas with a moisture content of less than 500 parts per million is suitable for stripping. A second electrolytic cell is used to remove moisture from the stripping gas before the bag, in turn, strips moisture from the liquid.

Important applications of CEC's moisture monitor are: the monitoring of moisture in jet fuel; the instant detection of moisture in catalytic reformer reeds, solvents in metal cleaning systems, transformer oil where dielectric properties are critical, hydraulic system oils, refrigerants, foods, and in distillation or extraction systems.

Circle No. 75 on Inquiry Card

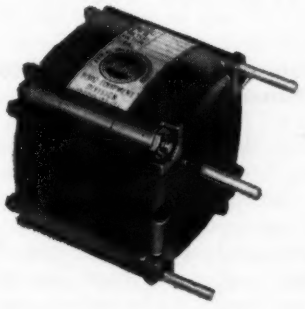
CIRCUIT QUALITY CONTROL

Contaminants Fluoresce Under Black Light

Did you know that solder flux, brazing flux, welding slag and other materials used in intricate electronic equipment fluoresce under black light? Black Light Corp. of America says these materials act like "built-in light beacons," often revealing that the equipment is not as clean as expected. If not removed they act as soils and contaminants. They can cause corrosion and current leakage and prevent firm adhesion of potting compounds. Black Light Corp, recommends monitoring the cleaning process by checking with black light. They say that a curtained booth with some diffused white light, near the cleaning process, is an ideal inspection area. Suggested black inspection check points are: 1) after sub-contractor completes blank circuit board; 2) when prime contractor receives blank board 3) during cleaning process after mounting components on printed circuit and, 4) before user installs printed circuit.

Circle No. 94 on Inquiry Card.

. . . electrocardiograph equipment— another Borg Motor application.



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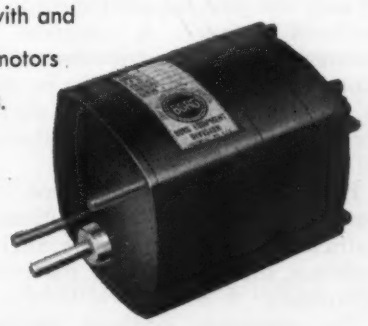

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RESEARCH

MATRIC CALCULUS COMPUTER

1 to 1 Correspondence Between Network Components and Matric Entries

Washington University in St. Louis reports that the first matric calculus computer to work with both general matric equations and with differential and integral calculus equations has been developed by Pierre M. Honnell, Washington University professor of electrical engineering, and his doctoral students.

An expanded program of research and development of the computer will get underway this fall in a computing devices research laboratory which is being established in the school's new Engineering Laboratory Building.

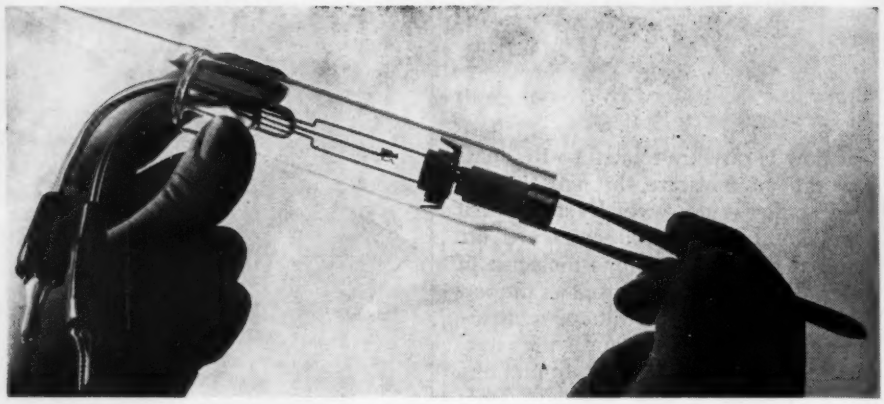
While digital computers use the fundamental mathematical concepts of adding and subtracting almost exclusively in their operation, matric equation analyzers work with entire equation systems instead.

Advantages of the matric calculus, Honnell says, are conciseness and generability of notation, high analytical power and wide applicability. Formerly used primarily in mathematical research, matric methods now are applied with increasing frequency to scientific problems in physics, dynamics, electric networks and econometrics.

The theory behind Honnell's computer is based on the synthesis of electronic (i.e.), active networks on an admittance basis. The basis is such that each matric entry of the mathematical equations being solved is represented by only one physical component in the synthesis network. A complete homeomorphism or 1 to 1 correspondence exists, which theoretically can be made as exact as desired, between physical network components and mathematical matric entries.

Honnell's theory synthesized networks which exhibit the solutions of matrically-formulated mathematical problems, such as system of differential equations.

The electronic synthesis networks can be ordered physically to show a complete isomorphism between the adjustable physical network components and the mathematical elements of the problem to be solved. In other words, the machine problem control panel can be designed in the typical mathematical matric array.



This experimental electronic tube, under early development at the Westinghouse research laboratories, gets its all-essential supply of electrons from a tiny crystal of silicon carbide no larger than the head of a pin. The crystal replaces the hot, power-consuming cathode usually found in conventional electronic tubes. The tube depends upon a new form of electron emission discovered in a semiconductor material, silicon carbide. Successful application of the discovery would result in a "solid state" electronic tube that would combine into a single device many of the advantages both of semiconductors and vacuum tubes. The silicon carbide crystal is inside the cartridge being inserted into the tube.

NEW ELECTRON SOURCE

Electronic Tubes May Some Day Be "Transistorized"

Physicists discovered recently that a constant flow of electrons can be obtained directly out of the surface of certain semiconductor materials. The latest semiconductor to yield this effect, is silicon carbide—a hard, crystalline solid best known for its widespread use in impure form, as an abrasive in grinding wheels. Density of the electron flow or "emission" is equal to that in the average electronic tube. The discovery was made by two research physicists, Dr. W. J. Choyke and Dr. Lyle Patrick, of Westinghouse Res. Labs.

"In recent years, transistors and related devices have replaced conventional electronic tubes in a wide variety of modern electronic equipment," Dr. Clarence Zener, director of Westinghouse research, said in disclosing the new discovery. "By removing the most serious limitation of the ordinary electronic tube, this discovery in semiconductors might reverse this trend and bring a new lease on life to the very device which semiconductors seem destined to outmode."

"Applied successfully to a vacuum tube, this new method of electron emission from semiconductors would do away with the whole inefficient process of boiling electrons out of a coated metal wire, or cathode, at high temperatures," Dr. Zener declared. "One can visualize a tube in which the usual heated cathode is replaced by a small semiconductor crystal having a built-in 'junction' like that in a transistor. The crystal would consume a negligible amount of power and would yield electrons instantly and indefinitely when a small voltage is applied across it."

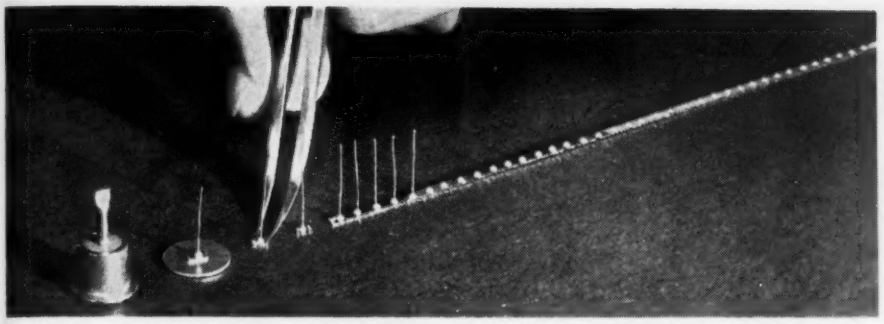
The escape of electrons from silicon carbide accompanies the emission of visible light from the crystal. This visible light is a form of electroluminescence, and occurs when enough voltage is applied across the junction to cause breakdown, that is, loss of the junction's normal electrical resistance.

When breakdown occurs, small blue spots of light appear in the crystal in the region of the junction. Electrons escape from these bright, light-emitting spots, especially from those located nearest the surface of the crystal. The spots are small, only about 50 millionths of an inch in diameter. From the spots the Westinghouse scientists have measured currents up to one millionth of an ampere, which indicates that the density of the electron flow is quite comparable to that from the cathode of a typical vacuum tube.

It is particularly interesting that this perfectly adequate flow of electrons originates from a tiny, pin-point source. Such a source would have many advantages in the construction of complicated tubes. It would simplify focusing of the electron beam and eliminate much of the complicated tube construction now employed for this purpose.

In view of the present-day emphasis upon miniaturization of electronic equipment, elimination of the large, hot, power-consuming cathode would be a major advance in electronic tube development. The potential advantages of such a "solid state" tube has stimulated at the Westinghouse research laboratories further research on the electron emission from silicon carbide as well as a program aimed at making eventual use of the phenomenon.

Circle No. 96 on Inquiry Card



A new method for growing germanium and other semiconductor materials, discovered by scientists at the Westinghouse research laboratories, may make the manufacture of transistors and similar semiconductor devices fully automatic. This "hand built" version shows how it might be done. The devices are formed as a continuous series of dots along the long, thin, mirror-flat surface of the crystal. Electrical connections are then made to the dots, after which they are separated from the germanium strip. Placing the unit in a plastic or metal container completes the process. Westinghouse scientists see no reason why the whole process cannot eventually be done automatically by machine at high speed and with high reliability.

GERMANIUM DENDRITES

A "Molecular Electronics" Material

Another very promising semiconductor development by Westinghouse scientists was disclosed by Dr. S. W. Herwald, Westinghouse vice-president-research. They have constructed long ribbons of semiconductor devices by forming them along the surface of long, thin crystals of germanium about an eighth inch wide and a few thousandths of an inch thick. Such construction appears to be feasible for the automatic production of transistors and other solid state devices directly by machine.

"These devices demonstrate the ultimate usefulness of a revolutionary new method for growing germanium which was recently discovered in our laboratories," Dr. Herwald said. "This technique grows the germanium as thin, flat continuous strips, or dendrites—the exact form in which it can be used directly in finished semiconductor devices.

"The unique continuous form of these dendrites, their remarkable uniformity, and their freedom from complicated processing make them unusually attractive, not only for automatic processing into useful devices, but also for the building of the most advanced kind of electronic systems."

Conventionally, germanium is grown as a thick, round ingot that requires costly, time-consuming processing to produce useful devices from it. In contrast, such devices can be constructed directly on the smooth, mirror-like surfaces of germanium dendrites exactly as the material is grown.

The development of working devices from dendrites is being carried out under a $2 million "molecular electronics" contract recently awarded to Westinghouse by the Air Force's Air Research and Development Command, Dr. Herwald reported.

Carried through to the development of over-all systems, the molecular electronics concept could drastically reduce the size, weight and power consumption of electronic systems. This concept involves a new understanding of the basic nature and capabilities of materials and a new approach—on a molecular and atomic scale—to the conception, design and development of materials that exhibit these capabilities.

"In molecular electronics one seeks to combine several separate electronic functions into a single operating unit that duplicates their over-all electrical behavior," Dr. Herwald explained. "For example, one can conceive of a single tiny slab of solid material that performs the function of a combination of transistors, resistors, capacitors, plus other circuit components, and yet contains none of these as actual entities.

"To perform such an operation, a solid state device must reach an entierly new order of perfection. Conventional ingots of semiconductor materials, which must go through tedious and complicated manufacturing procedures, are not likely to yield the near-perfect devices required for the job.

"Crystalline dendrites can make such units possible. Their quality is more uniform because of the unique way in which they grow; furthermore, their desirable properties are not jeopardized by long and complex processing into usable form.

"These characteristics, and the fact that they grow as high-quality continuous ribbons, make dendrites also appear to be the only form of material that now looks feasible for the fully automatic production of semiconductor devices."

Circle No. 97 on Inquiry Card

COMING

NEXT MONTH

October, 1959

Components Digest 8

Part II

Electromechanical Switches

November, 1959

Components Digest 10

Microwave Switches

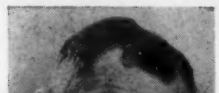
December, 1959

Components Digest 11

Materials and Techniques for High Temperature Components

MATERIALS

STAFF COLUMNIST



WHAT'S IN A CUBIC MICRON?

David Bandel
Associate Technical Director,
TRACERLAB, INC.

The chemistry of trace "impurities" has rapidly assumed a position of prime importance in materials technology. The term "impurities" in some instances is a hangover from one of the instinctive drives of the chemist; to obtain elements and compounds that are absolutely pure, that do not contain any foreign atoms. This drive has led the chemist to devise all varieties of ingenious procedures for detecting and measuring the quantities of trace impurities in very pure materials.

Materials technology has benefited in an important way from these advances in trace element analysis. The development of solid state devices such as semi-conductors, electroluminescent and phosphorescent materials depends heavily upon the ability to control very small concentrations of "impurities" in a high purity solid matrix. The development of high temperature and corrosion resistance metals has caught its second wind by the recognition of the profound effects that small traces of impurities can exert on the ultimate physical properties of metals and alloys. In particular, small quantities of oxygen and hydrogen may spell the difference between a substandard lump of metal and a high performance material. The deleterious effect of oxygen on the conductivity of copper has been recognized for several decades. The control of oxygen and other gaseous impurities in metals by high vacuum fusion has made practical the use of many high performance metals to meet severe environmental requirements. Titanium and zirconium were mainly laboratory curiosities ten years ago. Minute concentrations of boron in certain superalloys have a marked effect upon the ultimate physical properties of these alloys.

The history of events, human or technological, is always written from a point of view, for it is the development or discovery of new institutions or tools that determines essentially the lines along which events will progress. So one might logically write the history of modern materials technology from the point of view of the analytical tools that the chemist has developed in his quest for purity. This quest has led him along the path of measuring the "impurities" as a means of establishing the purity of his materials.

The metallurgist recognized some time ago that his problems involved an additional variable of prime significance, the control of certain constituents in highly localized areas. In particular, the composition of the grain boundaries and precipitated phases determine many of the properties of alloys. The problem has been difficult to solve since there was no useful tool available to examine the differences in composition between the grains and the grain boundaries. Empirical practices are used to control the properties of alloys, where the gross composition is known, by heat treatment in controlled atmospheres, nitriding, carburization and similar processes. However, it has not been possible, until recently, to measure the effects of such treatments on the composition of the grain boundaries or precipitated phases.

The development of a new instrument, the electron probe microbeam analyzer, now bestows upon the metallurgist the power to examine in detail the composition of these most vital areas and will enable him to correlate the results of his empirical processes with something he can measure accurately. The potentialities of the electron probe microbeam analyzer were recognized immediately by the metallurgist, since he has been muttering prayers and offering burnt sacrifices for such an instrument ever since the importance of grain boundaries was recognized. In fact, this instrument, developed as a Ph.D. thesis by a French metallurgist, P. Castaing, is not limited in any way to metallurgical applications. There are many instances where only a very small quantity of material is available for exmination or highly localized areas must be examined where the ability of the electron probe microbeam analyzer can supply the answer rapidly and accurately. Micrometeorites are being analyzed very successfully by this technique.

Two important advantages of this technique are its non-destructive character and the ability to analyze an area of one micron in diameter (a micron is 10^{-4}cm). The penetration of the electron beam into the sample is limited by the stopping power of the matrix material and this is of the order of one micron, so that the volume of material scanned is about a cubic micron. Limitations of this technique are principally the difficulty in analyzing elements below sodium in atomic number and a lower limit of detectability of 0.1-1.0% depending upon the element sought and the matrix in which the element occurs. Actually, elements as low as carbon (atomic number 6) have been measured, but this requires special systems not easily adaptable to the measurement of higher atomic number elements.

PRINCIPLES OF OPERATION

The operational principles of the electron probe microbeam analyzer were well known thirty years ago. C. G. Barkla discovered in 1911 that the x-radiation of the elements had characteristic frequencies which were unique for each element. Two years later Mosely discovered that the square root of the characteristic x-radiation frequency was proportional to the atomic number of the element. In practice, an electron beam is used to bombard the surface of the sample and produce the characteristic x-radiation of the elements present in the sample. The composite x-radiation spectrum thus produced is analyzed in a crystal spectrometer, which separates each of the characteristic lines present. The wavelength, or frequency, identifies the element present and the intensity of the x-radiation is a function of the concentration of the element. Comparing the intensity of

the x-radiation with a known standard determines the concentration of the element.

Engineering-wise, the design of a useful instrument is quite complex. The electron beam must be focussed properly to maintain the desired diameter. Also, the electron beam intensity must be stabilized since the intensity of the excited x-radiation will vary with the electron beam intensity. An optical system must be designed to permit precise location of the areas to be analyzed and alignment with the electron beam. All this is done in a high vacuum, since the electron beam will be scattered and attenuated in air. Virtually all the instruments used to date in this country have been "home brew" affairs, starting with an electron microscope as the source of the electron beam. A commercial instrument, the Microsonde, is now available. It is manufactured in France by CAMECA, represented in the U. S. by Intercontinental Electronics Corporation, Mineola, New York.

TYPES OF PROBLEMS SOLVED

A few examples of the types of problems that have been investigated by the electron probe microbeam analyzer illustrate the potential utility of this technique. Most of these examples are drawn from the field of metallurgical research, since the metallurgists have been quick to grasp its obvious advantages.

Diffusion of metals is a natural subject for investigation by electron probe microbeam analysis. The procedure, extremely simple and rapid, subjects the diffusion couple under study to the selected conditions of temperature, time and other variables chosen for the experiment. A sample of each of the couples is then placed on the stage of the microprobe analyzer and scanned transversely across the interface. Since the scanning can be done in steps of one micron, it is possible to locate the boundary of the diffusion layer quite precisely and determine the rates of diffusion with an accuracy difficult to approach by other procedures. The problem of metal diffusion is becoming increasingly important in high temperature materials as the temperature limits are raised.

The same technique can be used to estimate the thickness of oxide layers on metals, the nature of the interface of ceramic clad metals, and similar problems where a concentration gradient can exist across small distances. Segregation of alloy constituents in the various phases can be detected and measured rapidly by this technique. A similar problem that has been attacked by the microbeam analyzer is the composition of scale and metal inclusions. Analysis of welds has been extremely helpful in determining the cause of poor weldability of certain alloys or in pointing out the conditions under which good welds could be obtained.

The general analysis of very small particles of material is a natural application of microbeam analysis. The nondestructive nature of this technique is an extremely valuable feature in many instances. The extremely high distance resolution of the one micron beam can be used to study the nature of the junction type semi-conductors to determine diffusion patterns. Many other applications of this ingenious instrument will suggest themselves to technologists in various fields; it is too good a thing to permit the metallurgists to hog it all for themselves.

So, if you want to know what is in a cubic micron of matter, just ask the electron probe microbeam analyzer. The chances are you can get the answer.

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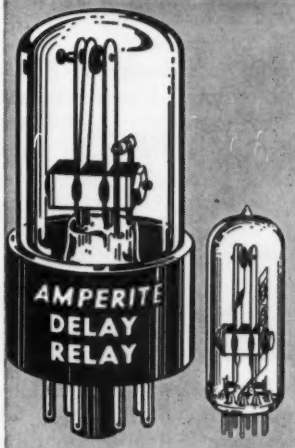

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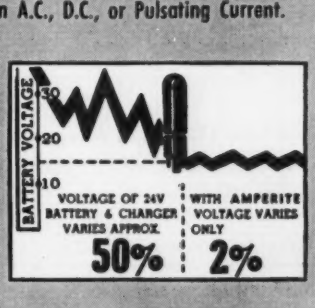

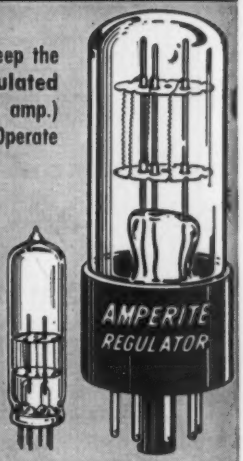

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GENERALIZED DYNAMIC LOAD CHARACTERISTICS

By
C. H. Pearsall Jr., Research Engineer
Fairchild Astrionics Div.
Fairchild Engine and Airplane Corp.

In our Jan.-Feb., 1958 issue, Sidney Davis presented a novel approach to calculation of the dynamic behavior of electric motors based upon a dynamic load characteristic (DLC) for each individual motor. Using the DLC it is possible to immediately ascertain the suitability of the motor and the optimum gear ratio for driving and accelerating a combined friction and inertial load. Mr. C. H. Pearsall, Jr., of Fairchild Astronics Division here presents an improved analytic method resulting in universal curves for immediate application to servomotors.

The dynamic load characteristics introduced by S. Davis in the article, "DLC of electric motors", Electromechanical Design, Jan.-Feb., 1958 is an extremely useful representation of a servomotor under load. It allows the designer to find the available power from the motor and the optimum gear ratio for any load acceleration to velocity ratio. The usefulness of this characteristic results from two facts:

- The acceleration to velocity ratio is unchanged between load and motor.
- At some speed, a maximum available output from a motor is obtained for a given acceleration to velocity ratio.

The purpose of this article is to extend the DLC technique and to indicate the applicability of the DLC when the motor is operated at less than balanced conditions. This latter condition, often encountered in practice, is easily handled by the practical equations describing servomotor performance furnished by S. Davis in "Two phase motors", Electrical Manufacturing, Sept., 1956.

On a normalized basis, the torque obtainable from a motor as a function of speed is given by:

$$t_K = K + d[1 + K^2)/2]\nu + K m\nu^2 \quad (1)$$
$$= K + d'\nu + m'\nu^2$$

where $d = 4\gamma - 1$ (2)

$m = -4\gamma$ (3)

and where $t = T/T_s$ is the normalized torque

T_s is the stall torque

$\nu = N/N_o$ is the normalized speed

N_o is the no-load speed

K is a factor giving percentage of rated voltage

γ is a factor representing the curvature of the torque-speed curve

The coefficient of ν, namely d', is a measure of the "linearized damping" of the unit.

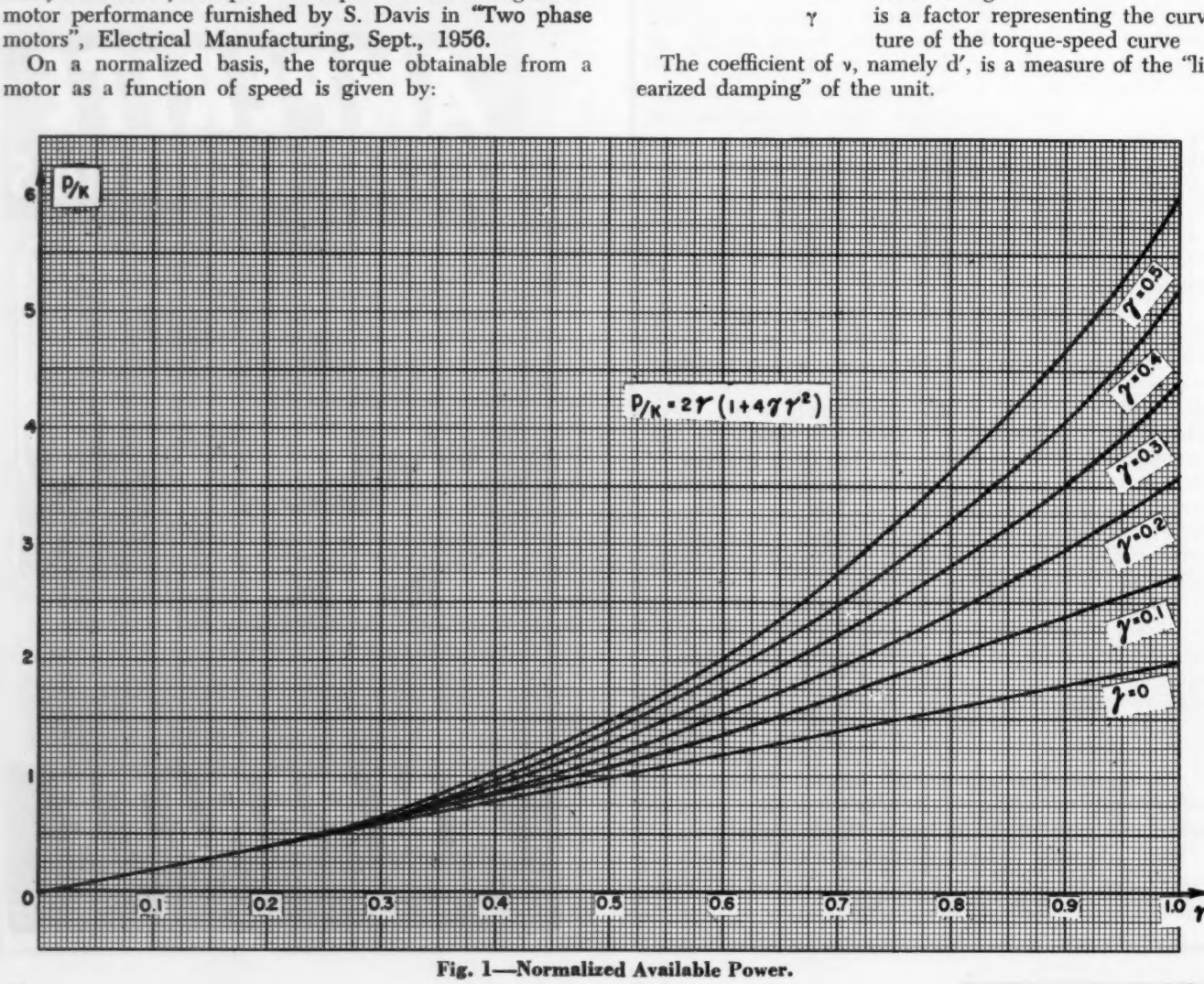

Fig. 1—Normalized Available Power.

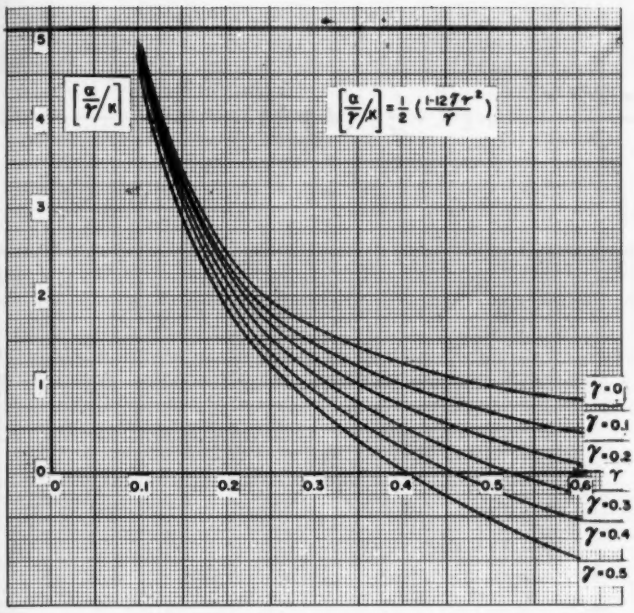

Fig. 2—Normalized Acceleration To Speed Ratio vs. Normalized Speed.

TABLE I

Table of constant C

K \ γ		+ 0.5	0.4	0.5
		− 0.0	0.1	0.2
1	Use Sign	2.00	1.20	0.40
0.9		2.01	1.21	0.40
0.8		2.05	1.23	0.41
0.7		2.13	1.28	0.426
0.6		2.27	1.36	0.454
0.5		2.50	1.50	0.500

$$C=\frac{1}{2}\quad(4\gamma-1)\quad\left(\frac{1}{K}+K\right)$$

The general normalized power equation is given by:

$$p = 4\nu(t-\alpha) \tag{4}$$

where $\alpha = \alpha/A_s$ is the normalized angular acceleration

A_s is the "theoretical stall acceleration"

$p = P/P_o$ is the normalized power

$P_o = \frac{1}{4}N_oT_s$ is the maximum power for a straight line speed-torque characteristic

J is the inertia

Also two useful conversion formulas are given:

$$P_o = (1/5408)N_oT_s \tag{5}$$

$$A_s = 386\,T_s/J \tag{6}$$

where

T_s is in units of oz-in

N_o is in units of rpm

P_o is in units of watts

J is in units of oz.-in.^{2}

A_s is in units of rad/sec.^{2}

The optimum operating points occurs when the tangent to curve (4) plotted as α vs ν with p as the family parame-

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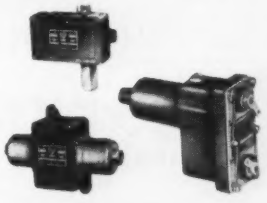

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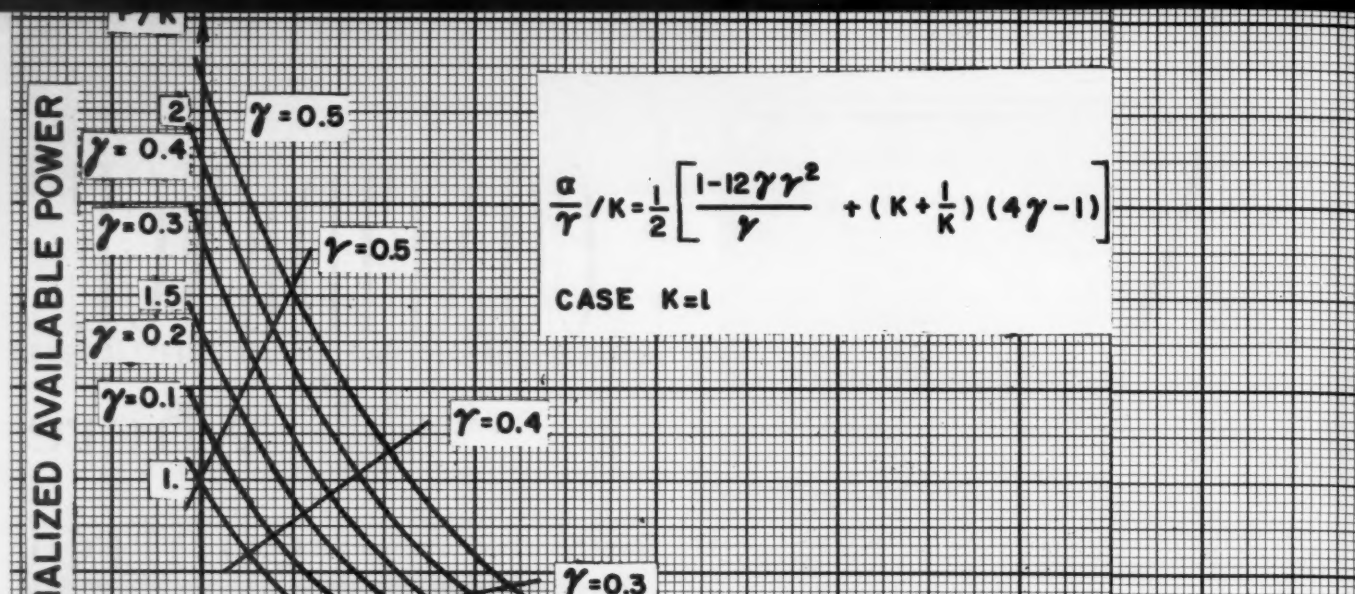

Fig. 3—Generalized DCL Curves.

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TABLE II
Typical Data on Servomotors

Type	Rating	Frequency	J	T_s	A_s	N_0	γ
Diehl							
FPE25-32-1	2w	60cps	0.098	4.8	18,700	1720	0.173
FPE49-7	10	60cps	0.58	12.2	8,120	3600	0.316
FPF66-11-1	50	60cps	1.25	60	18,500	3600	0.416
FPF85-18-1	100	60cps	2.15	96	17,000	4000	0.315
ZP162-2207-1	750	60cps	57.0	1620	11,000	1800	0.355
FPF49-19-1	25	400	17.4	17.4	11,650	8000	0.26
FPF85-16-1	100	400	2.15	48	8,600	8000	0.36
FPE25-79-1	10	60	0.14	12.3	34,100	3600	0.31
FPE49-58-1	25	60	0.76	29	14,750	3600	0.30
ZP162-2209-1	750	400	57.0	360	2,440	8000	0.4
US NAV BuOr							
MK7 MdO	0.8w	400	3.3	1.68	31,000	5300	0.15
MK14 Md 2	2	400	1.07	0.67	41,500	6400	0.07
John Oster Series							
5100-2237	40w	400	50	23	34,000	10,000	0.27
LO-Inertia	0.2	400	0.003	0.13	13,700	10,000	0.22
Servomechanisms							
Type 11P	1	400	1.4	0.63	31,000	6800	0.13
Type 10S2	0.4	400	0.46	0.33	49,000	6800	0.04

ter is α/ν. That is, for a given α/ν ratio, what is the maximum available power at a particular speed? Or, for a given α/ν ratio and a desired amount of power, what is ν in order that the optimum gear ratio can be chosen? The above considerations are pertinent to an estimate of the adequacy of the selected motor. Performing this operation:

$$t = K + d'\nu + m'\nu^2 \quad (7)$$

or $$\alpha = t - p/4\nu = K + d'\nu + m'\nu^2 - p/4\nu \quad (8)$$

differentiating $$d\alpha/d\nu = d' + 2m'\nu + p/4\nu^2 = d/\nu \quad (9)$$

yields $d'\nu + 2m'\nu^2 + p/4\nu = K + d'\nu + m'\nu^2 - p/4\nu$

$$p/2\nu = K - m'\nu^2 = K(1 + 4\gamma\nu^2)$$

Let $$C = [(1 + K)/K][(4\gamma - 1)/2]$$

or $$\alpha = (K/2)[1 - 12\gamma\nu^2] + KC\nu$$

then the final equations are:

$$p/K = 2\nu(1 + 4\gamma\,\nu^2) \qquad (10)$$

$$(\alpha/\nu)/K = (1/2)\,[(1 - 12\gamma\nu^2/\nu] \qquad (11)$$

For most servomotors, γ lies in the range $0 \leqslant \gamma < 0.5$, and we shall usually operate with $K = 1$ but under special conditions (eg. with limited transistor drive), K could be useful in the range $0.5 \leqslant K \leqslant 1$. For the case K approaching zero (near null condition), the K normalized equations are not useful since the term $K + (1/K)$ increases without bound. Therefore, multiplication of (10), (11) through by K eliminates this difficulty since the first term in (11) is proportional to K and in (10) is proportional to K, while the second term in (11) approaches a constant $[(4\gamma - 1)/2]$.

The separate curves of p/K and $[(\alpha/\nu)/K] - C$ are given for reference in Figs. 1 and 2, respectively. When the parameter ν is eliminated, universal DLC's result (see Fig. 3). A table showing the appropriate C as a function of K and of γ is given for reference in table I.

Inasmuch as the family of DLC's are normalized with respect to K, and K appears in the constant term of (11), the only effect of a K variation from the plotted value of $K = 1$ is to shift the normalized DLC curves in the horizontal direction. For example, K equal to the useful value of 0.5 yields a shift to the right a distance equal to 0.25 for the $\gamma = 0.5$ DLC. The normalized crossover is now $p/(1/2) = 3$ or effectively 3/2 whereas before $p = 2$ applied. Thus, a 25% reduction in the available power has occurred under the zero acceleration conditions. By using this technique, the variations with respect to K changes are easily visualized with precision.

Typical data on servomotors is given in table II for reference convenience. Additional data may be accumulated by the designer with the only effort being expanded in the calculation of γ.

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Starting with this column and continuing monthly, Electromechanical Design will publish excerpts from a manuscript by Mr. Olken constituting a course in the art of inventing. Mr. Olken proposes to cover a training program whereby engineers and scientists can educate themselves to increase their creative ability and productivity.

CHARACTERISTICS OF THE INVENTING PROCESS

The mental process of inventing is not a rigid, strictly logical (orderly) mental procedure. And no one has ever looked into an inventor's brain while the process is going on and seen how the wheels go around. However, from the literaure of those who have studied the creative mental process, and primarily from observations of those who have studied their own mental operations in creating an invention, certain characteristics of the process have come clear. A study of these characteristics can help point the way to improving our creative mental abilities.

CLEARING THE AIR

Before looking into what has been made known about the inventing process it would be profitable to clear the air and define the terms that we will use most commonly.

Engineering, Invention, Research. Throughout these columns we shall frequently have reference to three basic technical activities—"engineering," "research" and "invention." To most people these words are vague. The following explanations will assign distinct meanings to these terms so we can see them with clarity and precision.

Let us first consider what is signified by the terms "engineering" and "invention". Suppose, for example, you ask an engineer to design a conventional soaring airplane to meet a specified speed, rate of climb, ceiling, pay load, and so forth. The engineer will analyze the group of physical principles which in combination, make flight in heavier-than-air craft possible. That is, each principle is taken apart by itself (angle of incidence, angle of lift, and so forth) and proportioned to suit the specification requirements. Then all the different elements, each properly proportioned, are grouped together to provide the complete design. This is engineering.

But suppose that only the conventional soaring type of airplane is known, and you ask the designing engineer to devise a new type of airplane—one that rises by flying straight up instead of by soaring.. The known combination of scientific principles which produces soaring flight will not do. His problem now is to provide a new combination of physical principles that makes possible vertical flight. This is a problem of invention.

But invention and engineering alone are not enough to bring about the industrial success of technical developments. For example, DeForest combined the physical principle of a thermionic current flowing between plate and filament with the principle of a grid located between plate and filament to control the thermionic current. He thus invented a highly sensitive amplifier.

Engineers knew the laws of thermionic emission, so could proportion the filament to produce and specified current. They also knew the laws of space charge, so knew how to proportion the space between filament, grid and plate, and how much voltage to put on each. In other words, they knew how to take apart the combination of physical principles that made up the three-element vacuum tube, proportion each, then put them together again to produce a tube of any desired capacity.

However, it was found that only small, weak tubes, those that used less than about 45 volts on the plate, would work. In higher power tubes (using more than 45 volts on the plate) the thermionic currents to the plate became very erratic, and everything the tube amplified was highly distorted. Thus the combination of principles for the thermionic amplifier was known, the design principles were known, but only tubes of very small power could be built.

Irving Langmuir of the General Electric Company then did some systematic investigating, or research, and found the cause of this irregular behavior of three-element tubes at more than 45 plate volts. (Similar advances were made by both Arnold and Campbell of American Tel. & Tel. Co. See Blake, G. G., History of Radio Telegraphy and Telephone; also Maclauren, W. R., Invention and Innovation in the Radio Industry.) Langmuir discovered the irregularity was due to ionization of the gas inside the tube by the stream of electrons flowing toward the plate. So he removed the gas until a high vacuum existed inside the tube. Then the tubes behaved smoothly as amplifiers in sizes up to those having thousands of volts on the plate. High power amplifiers could then be built.

Thus we have definitions of the three functions necessary for the industrial success of any technological development:

- *Invention.* Forming a combination of scientific principles which makes possible the desired machine or process.
- *Engineering.* Breaking down this combination of principles into its elements, proportioning each to suit the specifications, then combining all to produce the final design.
- *Research.* Systematic investigation to discover unknown scientific facts or new scientific principles.

IDEA COMPOUNDS

Invention, as commonly understood by the psychologist, is the mental process of forming a group of lesser ideas, or idea elements, into a single idea combination or pattern. But the essence of the process is this: the idea elements are not merely stuck together, retaining their individual identities, as in a mosiac or in a mixture. Instead, during the inventing process a mental fusion or synthesis takes place and one resultant idea compound—one single, unifying concept—is formed out of the separate idea elements.

Idea compounds, like chemical compounds, differ considerably from their constituent elements. The principle difference is that things can be done with the idea compound that cannot be achieved with the elements by them-

selves. Thus Morse combined the idea of distant transmision of dots and dashes over an electric circuit with the idea of using the dots and dashes in an alphabetic code, to effect distant transmission of intelligence. With neither one of these ideas, by itself, is this result possible.

This process of synthesizing idea compounds from idea elements can be thought of as taking place in either of two ways:

- By forming NEW combinations from OLD (known) idea elements.
- By forming OLD combinations from NEW idea elements.

Thus when Morse invented the electric telegraph he effected a new idea combination for the distant transmission of intelligence. When Marconi invented the wireless telegraph he used a new idea element—the electromagnetic wave—to form the old combination made known by Morse.

The result of the inventing process does not always have to be a concrete, material thing such as a machine, a product or a process. An invention may be an abstract, intangible thing—often a useful mental tool, such as a mathematical technique or a scientific theory.

For example, Newton synthesized the idea element of algebraic procedure with another idea element—the theory of limits—into a single idea compound; a single, unifying concept—the calculus. He thus produced a powerful mathematical tool for solving the problems of science and engineering.

Similarly, Bohr combined the idea of the atom as a cluster of protons and electrons with the idea that the electrons rotate about the protons in distinct planetary orbits representing energy levels. The result was a single idea compound—a single concept of atomic structure which was one of the scientists most powerful mental tools for "cracking" the mysteries of nature and opening the way to the atomic age.

Hence an invention may be a concrete, material thing or an intangible mental abstraction. But in either case, we define it as the product of the mental process of inventing; namely, the synthesizing of idea elements into an idea compound, which idea compound makes possible things that are not possible with the unintegrated idea elements.

Psychologists have pointed out that this is the same process that occurs in all other fields of mental creation—in literature, music, science, etc. (See Ribot, T. A. Essay on the Creative Imagination. Open Court, Chicago, 1906.) For an excellent illustration of this point see the remarkable study, tracing the course of Coleridge's mind through the process of creating "The Ancient Mariner," made by J. L. Lowes in "The Road to Xanadu." Riverside Press, Boston, 1927.

INVENTIVE FACULTY

We also need, at the outset, a clear and common view of the equipment or faculty by which the mind carries on the inventive process. In line with current psychological thinking, I disagree with the common belief that the inventive faculty, or the aptitude for creating inventions, is a rare gift or special mental power passed on to a fortunate few by heredity. On the contrary, I hold with the psychologists that the inventive faculty is one common to nearly all of us; but as with all other human faculties it varies by fine gradations from one individual to another, over the range from the inventive ability of champions to the inventive ability of lame ducks. And, of course, as with other human faculties, the degree of capability of any individual's inventive faculty is the sum of the initial aptitude he inherited at birth plus the skill gained by exercise and training.

End of Part I

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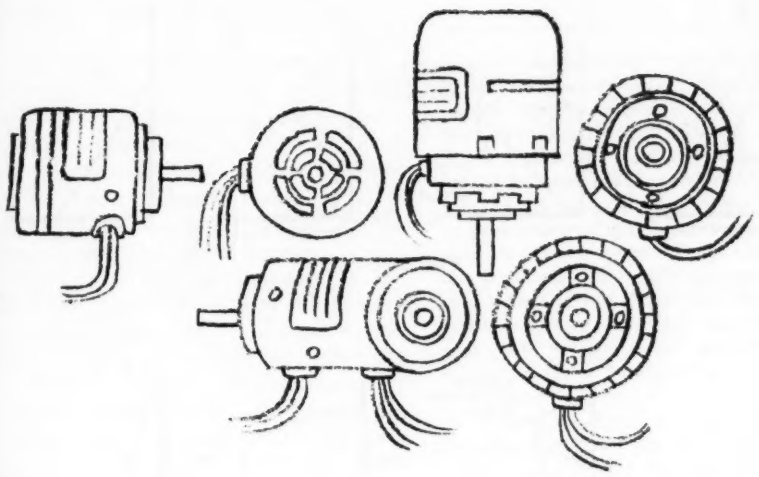


FRACTIONAL HORSEPOWER INDUCTION MOTORS

For Military Applications

Much has been written and many standards are available on classification and specification of commercial motors. Probably the most important documents in this field are the NEMA Standards which govern frame size, performance, and some design features of motors for commercial applications. This Components Digest emphasizes motors for military application in which high speed operation at extreme temperature, maximum output, and life of the order of one thousand to several thousand hours are important requirements. The presentation covers capacitor type units, self-cooled units, and gearhead-type units.

Because of their special importance and our policy of providing detailed coverage of a topic, this Components Digest is confined to squirrel cage induction motors. While these units lack the flexibility of d-c machines, their characteristic ruggedness, particularly, as a result of the absence of sliding brush contacts on the rotor, has lead to almost universal acceptance in critical applications.

Induction motors are available for both single-phase and polyphase service. Single-phase units most often include permanently connected capacitors to provide high starting torque and good running efficiency. The selection of a starting means requires a compromise between electrical performance on one hand and simplicity and low cost on the other.

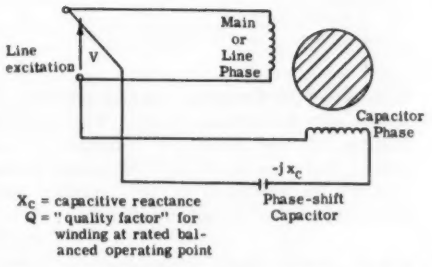


Fig. 1—Single-phase capacitor motor. At a given motor operating point, the voltage across the capacitor phase may be adjusted for perfect two-phase operation.

The permanent-split capacitor unit is wound the same as a 2-phase motor with a capacitor placed between one phase winding and the power supply and with the other phase connected directly across the power line. Fig. 1 lists important relationships for balanced operation. Motors of this type have modest starting torque, falling to approximately 30% of full load torque in larger units. The capacitor windings usually differ from the main phase to obtain optimum performance and capacitor size. Three lead motors of this type generally are unidirectional. Four lead motors may be reversed by switching two leads of either phase.

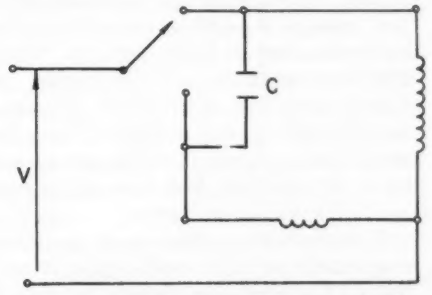


Fig. 2—Circuit for rapid reversal of a single phase permanent-split capacitor motor with a SPDT switch. The phases should be identical. In general this circuit is less efficient than that of Fig. 1 where better balancing is possible.

To obtain instantaneous reversal using a SPDT switch, both phases are wound identically and three leads are attached. Reversible rotation is readily obtained as shown in Fig. 2.

The power factor of a permanent-split capacitor motor is generally 95% to unity at full load. Occasionally power factor may be sacrificed for other requirements such as high starting torque, in which case it may drop below 95%.

To improve the starting characteristic of the permanent-split capacitor

COMPONENTS DIGEST

type motor, it is possible to use an external relay to put a second capacitor in parallel with the running capacitor during starting. This second capacitor is dropped out of the circuit as the motor reaches a pretermined speed or current value. By this means starting torques in the magnitude of 500% are obtainable. The major limitation of this system is the externally mounted relay and two capacitors. The volume of these three parts may approach that of the motor, and costs have run as high as 75% of the motor.

Capacitor start-induction run motors are available in the middle and larger frame sizes. This type uses a capacitor only to start and then runs as a straight single phase motor. It has been found preferable to use current or voltage sensitive relays instead of centrifugal switches. Induction motors of this type have high starting torque and are used primarily in 60 cycle units. Some radio interference is encountered and this must be considered in applying the motor.

Three-phase motors give the greatest horsepower per weight and are the most stable type discussed here. Excellent starting torque characteristics are obtained with normal starting torques ranging from 250 to 300%. Higher starting torques are readily obtained at some sacrifice of size and weight. Efficiency is higher than for single-phase motors but the power factor is considerably less than for permanent-split capacitor types.

Three-phase stators are generally connected wye (Y) with either 3 or 4 leads. Voltages are shown in Fig. 3 for a 200 volt motor. Occasionally 115-volts line-to-line wye-connected motors are required. In this case only 3 leads are furnished since the neutral of the power supply is seldom available.

Table 1 shows performance characteristics of the commoner miniature drive motors, including some d-c types for comparison purposes. On the a-c units, no-load speed is always somewhat lower than synchronous speed given by the equation:

$$\text{Synchronous rpm} = \frac{120 \times \text{frequency (cps)}}{\text{poles}}$$

Speed is usually defined in terms of slip which is the per-unit reduction in speed below synchronous speed. Induction motors operate at low slips except for occasional instances where high slip characteristics may be required. High slip units are inefficient but they are necessary in some applications as will be described later.

Table 2 lists the average range of operating speeds of small low-slip induction motors.

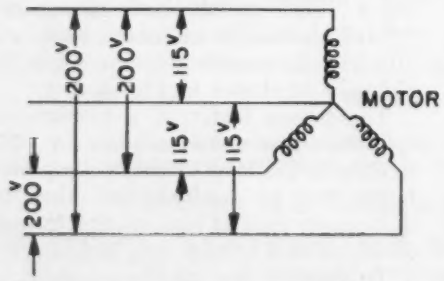


Fig. 3—Three phase motor schematic.

TABLE I

TYPICAL SPEED TORQUE CURVES FOR F.H.P. MOTORS

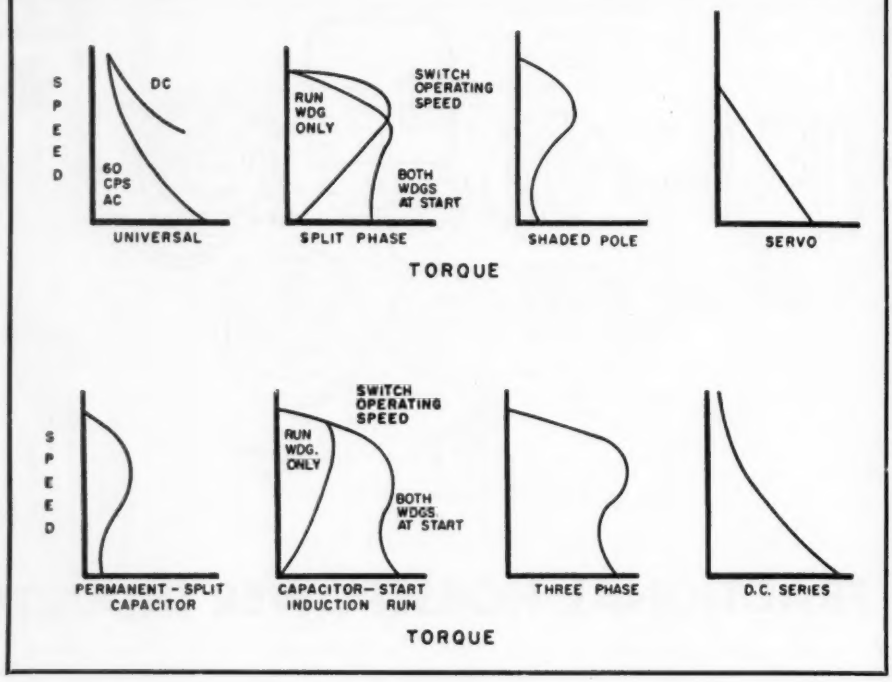


Fig. 4—Speed-torque characteristic of a low slip induction motor. The dashed region of the curve is considered unstable because a stable operating point cannot be achieved in this region with many types of driven load.

TABLE II

Approximate Induction Motor Speeds* (rpm)

No. of Poles	400 Cycles	60 Cycles
2	20,000-21,700	3000-3250
4	10,300-10,800	1550-1625
6	7000-7200	1050-1075
8	5300-5400	800-825

**Speeds are less than synchronous speed for poles and frequency. Depend upon horsepower rating, number of phases, starting torque, and other application details.*

INDUCTION MOTOR CHARACTERISTICS

Fig. 4 shows the speed-torque characteristic of a typical low-slip induction motor. Peak or pull-out torque occurs somewhat below synchronous speed, the rated operative point lying between the peak torque and no-load points. The starting torque varies with the type of starting means provided, as shown in Table 1. In general polyphase units provide better starting than single-phase units. High starting torque requires a design compromise with running efficiency at rated load. This is particularly true with permanent-split capacitor type units, where selection of the capacitor must be made as an optimum compromise between starting and running requirements.

POWER SUPPLY REQUIREMENTS

Most aircraft and military applications have a power source in accordance with type-1 power of MIL-E-7894A (ASG). This calls for 400 cps ±5%. A motor designed for this type of pow-

er supply will operate from 380 to 420 cycles (400 ±5% cycles), but not necessarily the same as at 400 cycles.

Other common frequencies are:
60 cycles – commercial, ground based equipment and Navy MIL-M-17059 (ships)
416 cycles – Navy standard, although a lot of 400 cycle used.
1600 cycle–Some navigational and radar equipment

Variable frequency is required in some applications. Where used, variable frequency motors are generally of the permanent-split capacitor type.

Voltage ratings in general do not affect performance except when they become extreme. High voltages in particular may lead to wire sizes that are too fine to handle in manufacturing and are unreliable in use. Special insulation may be required adding to cost as well as building up the winding volume, a factor of importance in very small motors, and capacitor voltage ratings must be correspondingly high. Only occasionally is there a limitation on the low voltage unit, where wire may become too heavy for easy handling. For similar rating, doubling rated voltage means using a wire 3 sizes finer.

The common single-phase voltage is 115 volts for both 400 and 60 cycle units. Three phase motors are generally 200 volts line-to-line and/or 115 volts line to neutral.

A system designation of 115/200 volts required a 4-lead, 3-phase motor rated 200 volts line-to-line as shown in Fig. 4. In some applications the neutral lead is not required and, therefore, only three leads are furnished.

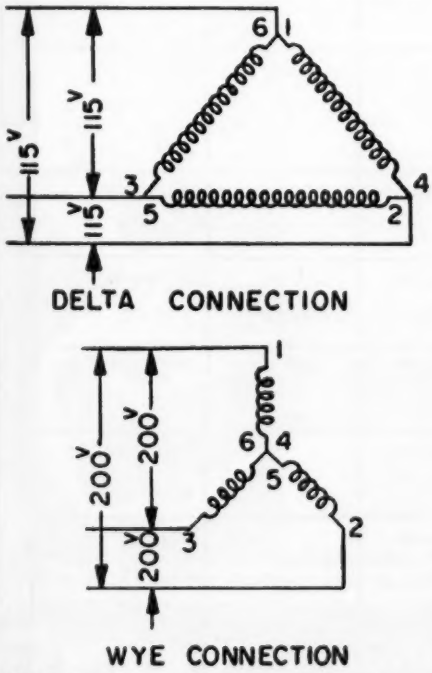


Fig. 5—Alternate connections for a 3-phase motor for operation at two different voltages.

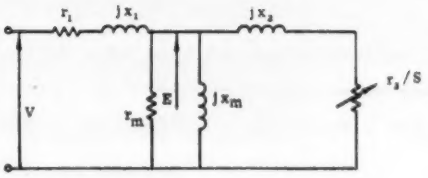


Fig. 6—Equivalent circuit of one phase of a polyphase induction motor under balanced operating conditions. In the diagram, Y_1 is the stator resistance; X_1 is the stator leakage reactance; X_m is the airgap reactance; r_m is the core loss resistor; r_2 is the rotor resistance referred to stator; X_2 is the rotor leakage reactance referred to stator; V is the applied phase voltage, and S is the slip which is the difference between the speed of the rotating magnetic field and the rotor speed divided by the speed of the rotating magnetic field.

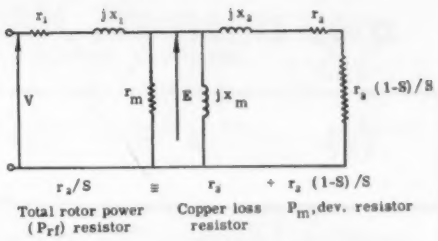


Fig. 7—Modified Equivalent Circuit. The above circuit differs from Fig. 6 in that the total power to the rotor is represented as the sum of two powers: that due to rotor copper loss (resistor r_2), and that due to developed mechanical power (resistor r_2 [(1-S)/S]). The sum of these two resistors equals the r_2/S of Fig. 6. When r_2 [(1-S)/S] is equal (as S varies) to the reflected source impedance seen from its terminals (V short circuited), P_m,dev. is maximum. By equation (3) of Table IV, it may be seen that maximum torque is developed when r_2/S equals the reflected source impedance. Since the reflected impedance is not a function of r_2, maximum torque is neither As a matter of fact, the slip shown on the speed-torque curve is merely increased proportionately with r_2.

In either case, the stator winding is not grounded inside the motor frame.

Occasionally it is advantageous to have a motor that will perform essentially the same at two different voltages. Such motors are called dual voltage units and generally have stators wound so that they may be connected delta (Δ) or wye (Y). The lower voltage is applied to the delta connection and the higher voltage to the wye connection. Figure 5 shows such a connection. Note that six (6) motor leads are required. The ratio of the low and the high voltage is the square root of 3 (i.e.: 115/200).

Where voltage and frequency vary, performance can be considerably affected. This factor is often ignored in critical applications. Motors may overheat at one extreme of voltage and frequency, and fail to deliver adequate output at the other. Table 3 provides a concise summary of the affects of power supply variation on performance.

BASIC PRINCIPLES OF INDUCTION MOTORS

To fully understand the points to be developed in this Components Digest, it is important to review concisely the basic operating principles of induction motors. At first we consider the balanced polyphase induction machine for which a simple, well-developed theory exists. This is then extended to include various types of single-phase machines. With this background, it will be possible to understand the important relationships governing performance limits of induction machines.

Figs. 6 and 7 show the equivalent circuit of one phase of a polyphase induction motor operating under balanced conditions. Equivalent circuits such as these are very convenient in representing the performance of rotating machinery. The equivalent circuit elements correspond to specific motor design parameters. The equivalent circuit possesses the advantage that once its parameters are determined, either from design calculations or by measurement on an actual motor, it is a simple matter to calculate all performance characteristics with no further reference to the actual machine. This procedure reduces motor performance calculations to a straightforward circuit analysis problem. Furthermore, changes in the parameters of the equivalent circuit may be related with ease to corresponding changes in the actual machine. The equivalent circuit is a design tool as well as a tool for analysis.

Table 4 concisely relates equivalent circuit parameters and machine performance. Items that are readily calculated include shaft torque, current and power, power factor, output power, and the individual losses as a function of slip. Notice the direct proportionality between outpue torque and power transferred to the rotor (power of the rotating field) and the inverse relationship between torque and synchronous speed. Low speed machines tend to have higher torques, although operative efficiency is generally less than for high speed machines.

CONCLUSIONS FROM THE EQUIVALENT CIRCUIT

Certain performance characteristics are determined by inspection of the equivalent circuit. The leakage and magnetizing reactances of 60-cycle motors are decidedly lower than for 400-cycle motors. This means more exciting cur-

TABLE III

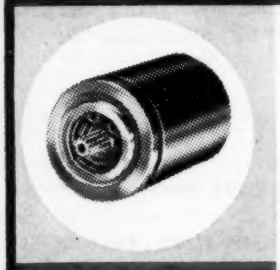
EFFECTS OF VOLTAGE AND FREQUENCY VARIATION ON INDUCTION MOTOR CHARACTERISTICS

Variation	120% voltage	110% voltage	Function of voltage	90% voltage	105% frequency	Function of frequency	95% frequency
Starting & max running torque	Increase 44%	Increase 21%	(Voltage) 2	Decrease 19%	Decrease 10%	1 / (Frequency)2	Increase 11%
Synchronous Speed	No change	No change	Constant	No change	Increase 5%	Frequency	Decrease 5%
% Slip	Decrease 30%	Decrease 17%	1 / (Voltage) 2	Increase 23%	Practically no change	.....	Practically no change
Full load speed	Increase 1.5%	Increase 1%	(Syn-speed slip)	Decrease 1-1/2%	Increase 5%	(Syn-speed slip)	Decrease 5%
Full load efficiency	Small increase	Increase 1/2 to 1 point	.....	Decrease 2 points	Slight increase	.....	Slight decrease
3/4 load efficiency	Decrease 1/2 to 2 points	Practically no change	.....	Practically no change	slight increase	.....	Slight decrease
1/2 load efficiency	Decrease 7 to 20 points	Decrease 1 to 2 points	.....	Increase 1 to 2 points	Slight increase	.....	Slight decrease
Full load power factor	Decrease 5 to 15 points	Decrease 3 points	.....	Increase 1 point	Slight increase	.....	Slight de crease
3/4 load power factor	Decrease 10 to 30 points	Decrease 4 points	.....	Increase 2 to 3 points	Slight increase	.....	Slight decrease
1/2 load power factor	Decrease 15 to 40 points	Decrease 5 to 6 points	.....	Increase 4 to 5 points	Slight increase	.....	Slight decrease
Full load current	Decrease 11%	Decrease 7%	.....	Increase 11%	Decrease slightly	.....	Increase slightly
Starting current	Increase 25%	Increase 10 to 12%	Voltage	Decrease 10 to 12%	Decrease 5 to 6%	1 / frequency	Increase 5 to 6%
Temp rise at full load	Decrease 5 to 6C	Decrease 3 to 4C	.....	Increase 6 to 7C	Decrease slightly		Increase slightly
Max overload cap	Increase 44%	Increase 21%	(voltage) 2	Decrease 19%	Decrease slightly		Increase slightly
Magnetic noise at no-load in particular	Noticeable increase	Increase slightly		Decrease slightly	Decrease slightly		Increase slightly

Note: This table shows general effects which will vary somewhat for specific ratings.

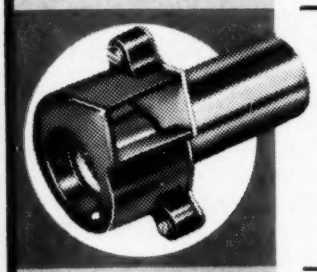
Courtesy Hertner Small Motors

IMC PRECISIONEERED MOTORS



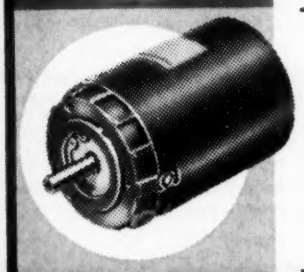
700 FRAME SERVO MOTOR

INPUT: 6-57 volts; 2 phase at 400 cps
FREQUENCY RANGE: 400-1000 cps
NUMBER OF POLES: 2, 4 and 6 poles
TYPICAL PERFORMANCE: 26/26 at 400 cps; No Load Speed: 6,200 rpm; Stall Torque: 0.30 oz. in.; Power: 3 watts/ϕ; Inertia: 0.65 gm cn^2; Acceleration: 33,000 rad/sec^2; Impedance: 133 + j117 ohms
WEIGHT: 1.6 ounces
DIMENSIONS: 0.750 Dia. x 1.062 Length
Bulletin 7F3



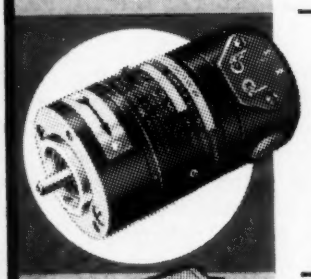
900 FRAME AC MOTOR

FREQUENCY: 320-1000 cps
AIR DELIVERY: (1½" Blower)*; 10 cfm @ 0"sp; 8 cfm @ 0.2"sp
RPM: 7000 @ 400 cps
WEIGHT OZ.: 7
WEIGHT OF MOTOR OZ.: 4½
*Also available in 1" blower size
Bulletin 9F4



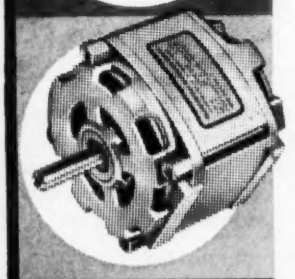
1600 FRAME MOTOR

HORSEPOWER: 1/300-1/10
FREQUENCY: 25-1000 cycles—var. 50-1000 cycles
VOLTAGE: 26-208
POLES: 2, 4, and 6 poles
PHASES: 1, 2, or 3
TYPES: Induction or Synchronous
BEARINGS: Ball or Sleeve
Available non-cooled or self-cooled
APPLICATIONS: Blower, Fan, Gear, Recording and Control



2000 FRAME DC MOTOR

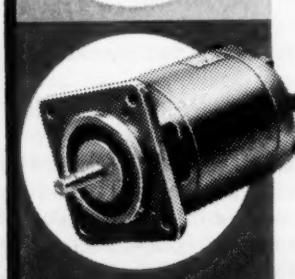
INPUT: 6-115 volts DC
OUTPUT POWER: 1/75 to 1/10 hp depending on speed, duty cycle and cooling
LIFE: 1000 hr brush life; 250 hrs at high altitude.
Available with gear speed reducer and/or speed governor, shunt, series, or compound wound.
Bulletin 20F2



2900 FRAME HYSTERESIS MOTOR

VOLTS:	115	**T.P.I. (oz.in.):**	4.5
CPS:	60	**T.P.O. (oz.in.):**	5.0
WATTS INPUT:	24	**T.St. (oz.in.):**	4.0
AMPERES:	.22	**CAPACITOR (mfd):** } **220 VOLTS A.C.:** }	2.5
NUMBER OF POLES:	4		
RPM:	1800	**WEIGHT:**	1 lb.
H.P.:	1/125		

Hysteresis Catalog



3800 FRAME AC MOTOR

INPUT: 26-230 volts AC; 1, 2 and 3 phase
INPUT FREQUENCY: 25-400 cycles
NUMBER OF POLES: 2, 4, 6, 8 and 12 poles
OUTPUT POWER: Induction motors—to 1 hp; Torque motors—10 to 200 oz. in. stall torque; Hysteresis synchronous motors—1/200 to 3/4 hp (can be wound for single, dual or three speed.)
BEARINGS: Ball or Sleeve
WEIGHT: 8-11 lbs.
MOUNTING: Round or square flange and/or base
Bulletin 38F6

IMC's versatile engineering staff is available to meet your specific design requirements.

imc Magnetics Corp.
Formerly Induction Motors Corp.
570 MAIN STREET/WESTBURY, L.I., N.Y./EDGEWOOD 4-7070 • 6058 WALKER AVE./MAYWOOD/CALIF.

CIRCLE 48 ON INQUIRY CARD

IMC Magnetics Corp.

New Name of INDUCTION MOTORS CORP.

Westbury, New York, August 17, 1959 —The management of Induction Motors Corp. has recently announced a change in the corporate name of IMC MAGNETICS CORP. In making the announcement, a company executive pointed out that with the acquisition of P.S.P. Engineering Company and Gray & Kuhn, Inc., the corporation's field of operation has been considerably broadened. He further stated that the new name of the company more closely defines the corporation's present activities.

The company spokesman indicated that P.S.P. Engineering Company operated in the field of electromechanical devices. According to company officials, this is particularly compatible with IMC's manufacturing and marketing activities. The same was said of Gray & Kuhn, Inc., manufacturers of time delay lines, pulse-forming networks and allied components.

It was disclosed that with these new additions, IMC MAGNETICS CORP. is now a more diversified enterprise, no longer confined to the manufacture of motors.

New Size 5 Servo Motor

Introduced by IMC MAGNETICS CORP.

Westbury, New York, August 17, 1959 —A size 5 servo motor with an exceptionally short overall length of one inch has been announced by IMC Magnetics Corp. Designed for servo systems where a miniature motor is required, the IMC unit meets the most rigid performance specifications.

Total Input Power — 3.5 watts

Theoretical Acceleration — 45,000 rad/sec

Stall Torque — .09 oz/in

Frequency — 400 cycles

No Load Speed — 9500 rpm

Temperature Range — —55°C to +150°C

The unit's small size of one inch length and 0.5 diameter is matched by a minimum weight of 0.68 ounces. For maximum protection against severe shock, vibration and humidity, the IMC size 5 has been completely encapsulated in epoxy.

For more information on the IMC MAGNETICS CORP. new servo motor:

CIRCLE 72 ON INQUIRY CARD

COMPONENTS DIGEST

rent for the 60-cycle motor indicating the need for smaller air gaps and fewer poles. The relationship between poles and exciting current may be developed by simple reasoning. If the stator winding is arranged to provide relatively few poles having a heavy concentration of turns per pole, then the number of flux linkages per pole is high since more of the turns link more of the flux. Where the winding is spread over many poles the flux per pole is naturally much reduced and the total linkages which determine overall reactance are correspondingly reduced, proving the point.

On the other hand, the torque per rotor watt is higher in low frequency motors in accordance with the basic torque formula of Table 4. Consequently for maximum torques a compromise is necessary in setting the number of poles. For a given frame size and frequency, fewer than the optimum number of poles means low torque per rotor watt while too many poles means high exciting current and reduced efficiency.

Where output power in a given frame size must be maximized, a high speed, high efficiency motor is indicated. A two-pole high frequency motor is apt to be more efficient than low frequency motors with more poles. However, there is an upper frequency limit at which losses in the motor iron become excessive causing loss in efficiency. (It is interesting to note that as the quality of motor lamination iron improves, the frequency for best efficiency increases. Motors today frequently operate at one and two thousand cycles.) Core losses in low frequency motors are often negligible since the magnetizing reactance shunting the core loss resistor in the equivalent circuit of Fig. 6 draws most of the current. The equivalent circuit of a small, low frequency motor may be approximated by omitting the leakage reactances and the core loss resistor.

Higher efficiencies generally obtained from high speed machines are often paid for in increased complexity of gear reduction units, poor stopping and reversing characteristics, more noise, and reduced bearing and gearing life. These factors must be considered in choosing the number of poles. Two-pole units are seldom used at 400 cps; they are frequently used at 60 cps.

The effect of varying rotor resistance is apparent from the equivalent circuit. Torque depends on the ratio of rotor resistance to slip. Doubling rotor resistance has the same effect as doubling the slip. This can be seen by examining Fig. 8 showing speed-torque characteristics for several rotor resistances. A low-resistance rotor is a low-slip rotor since rated torque is developed at close to synchronous speed.

The problem of determining maximum motor output is a simple circuit problem. For maximum torque r_2/s must match the circuit source impedance, with the input voltage replaced by an equivalent short circuit using Thevenin's Theorem. For a given rotor resistance the slip may be determined for maximum torque or vice-versa. For maximum power output, the power output resistor of Fig. 7 must match its source impedance, and the slip at which maximum power output occurs is readily determined.

These examples emphasize the importance of the equivalent circuit technique of replacing a complex machine with a simple passive circuit, substituting circuit power calculations for torque calculations in the machine, and applying impedance matching principles to the determination of maximum performance points in the machine.

TABLE IV
TWO-PHASE INDUCTION MOTOR AND EQUIVALENT CIRCUIT PRINCIPAL PERFORMANCE CHARACTERISTICS

Where Input Power Goes:	Equivalent Circuit	Induction Motor
	Power in r_1	Stator copper loss
	Power in r_m	Core loss
	Power in (r_2/S) (P_{RF})	Total Rotor Power

Developed Mechanical Power: Power to rotor consists of sum of developed mechanical power + rotor copper loss. This sum equals:

$$P_{RF} = I_2^2 (r_2/S) \equiv I_2^2 r_2 + I_2^2 r_2 [(1-S)/S]$$

(P_{RF}: Total rotor power; $I_2^2 r_2$: Rotor Copper Loss; $I_2^2 r_2 [(1-S)/S]$: Developed Mechanical Power $(P_{m,dev.})$; Algebraic Identity)

(1) $$\therefore P_{m,dev.} = I_2^2 [(r_2/S) - r_2] = I_2^2 r_2 [(1-S)/S] = P_{RF} [1-S]$$

Developed Torque By fundamental Mechanics:

(2) $$P_{m,dev.} = (T/12 \times 16) \times N \times (1/33{,}000) \times 746 \times 2\Pi = TN$$

Since $N = N_S (1-S)$, and $P_{m,dev.} = P_{RF} (1-S)$, by substituting in (2), T may be determined.

(3) $$T = (1352/N_S) P_{RF}$$

Maximum Developed Mechanical Power Since $P_{m,dev.}$ is equal to dissipation in r_2 $[(1-S)/S]$, $P_{m,dev.}$ reaches a maximum when r_2 $[(1-S)/S]$ equals the reflected source impedance.

Maximum Developed Torque Since T is proportional to dissipation in r_2/S, T reaches a maximum when r_2/S equals the reflected source impedance.

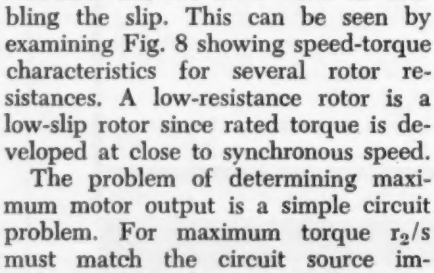


Fig. 8—Speed-torque curve of induction motor with varied rotor resistance. Curve C shows a characteristic suitable for servo-motor performance. Slip for corresponding torques is proportional to r_2. Curve B is typical of a high slip rotor where reasonable efficiency is still required.

MEASURING THE EQUIVALENT CIRCUIT

The equivalent circuit of an induction machine may be measured directly to establish its parameters. Standard texts on electrical machines list the steps involved in measuring and calculating the parameters. A comparison of calculated performance (from circuit parameters) and measured performance shows a complete picture of motor behavior. The measured equivalent circuit parameters provide a valuable tool for the analysis of a motor under non-standard operating conditions. If ambient temperature or frequency (or

some other parameter) were to vary, it would be possible to predict the effects of these variations on performance directly from the equivalent circuit. In any exceptionally complex motor application, a knowledge of the equivalent circuit is helpful.

SINGLE PHASE MACHINES

Single-phase motor performance may be explained by reference to the permanent-split capacitor type machine. When operated under fixed conditions of loading, frequency and speed they perform almost as efficiently as polyphase machines. Performance deteriorates, however, at other than the standard operating point. For optimum performance the capacitor shifts the phase 90 degrees and simultaneously provides rated voltage for balanced operation. For this condition the phase powers are equal and a condition is achieved similar to that of two-phase motor operation.

However, as speed changes the motor impedance is no longer fixed, upsetting the balance of power. At low speeds the main phase pulls excessive power while capacitor phase power is limited by the relatively high capacitor impedance. At high speeds, particularly at no load, the capacitor phase resonates building up a high voltage and puliing high watts while main phase power drops sharply. Because of voltages induced by rotation, considerable interaction occurs between the separate phases. The net effect of these unbalances is to reduce shaft output and efficiency at speeds other than the rated speed at which the capacitor was adjusted. Often the choice of capacitor represents a compromise for reasonable operation over a speed range rather than for optimum operation at any one point.

Analysis of the capacitor motor for balanced conditions is based upon conventional circuit theory. The complex winding impedances are known and the capacitor value required for a 90° phase shift is readily calculated. The ratio of capacitor winding to main field winding impedances equals Q^2, where Q is the conventional "quality factor" for the windings. This impedance ratio is established by adjusting turns. Voltage across the capacitor phase equals Q times line voltage. Other relations are shown on Figure 1.

As load and speed vary, the phases unbalance, winding impedances change, and there is a loss of torque, a reduction of the no-load speed, and increased losses due to unbalance.

UNBALANCED OPERATION

Symmetrical component theory holds that unbalanced voltages applied to an electrical machine may be replaced by sets of balanced polyphase voltages of opposite phase sequence. Therefore the behavior of an induction machine under balanced conditions may be explained in terms of its response to the simultaneous application of balanced but oppositely phased voltage sets developing their individual torques at any specified slip.

The capacitor motor described above operates in general under unbalanced conditions keeping neither a 90° phase shift nor balanced phase power. The machine behaves as if there were simultaneous positively and negatively rotating fields. Presumably the positively rotating field predominates and the unit rotates in the required direction although it is conceivable that a direction reversal can take place by an appropriate selection of capacitor. The negatively rotating field subtracts torque from the output and induces extraneous voltages and losses in the rotor. These losses arc high because of the high slip between the rotor and the negatively rotating field. Unfortunately, not too much can be done about these losses. They are particularly severe in low resistance rotors which are designed for high operating efficiency at low-slip. As in many engineering problems, compromise is necessary.

DYNAMIC LOAD CHARACTERISTICS

There are some applications where load acceleration, inertia, friction and speed are simultaneously specified. In these applications, the engineer must choose a suitable motor and gear reduction ratio. The wattage or horsepower rating of the motor is not a sufficient basis for selection; its inertia is a significant factor.

The selection of motor and gear reduction is based upon the fundamentals of mechanics and has been well covered in many techcnical papers. A recently developed technique of exceptional simplicity based upon a Dynamic Load Characteristic (DLC) is described here as a supplement to existing methods. The general shape of the DLC is shown in Fig. 9. The abscissa is the ratio of load acceleration to load velocity in any arbitrary set of units. The ordinate to the curve represents power available for driving the load. The shape of the curve (decreasing with increasing abscissa) shows the loss in available output with increasing acceleration, corresponding to the increasing component of shaft power required to accelerate the motor itself. The operative point also indicates motor speed; the ratio to load speed is the reduction ratio required for optimum performance. By means of the DLC, an engineer may at a glance check the suitability of a given motor, and establish the required gear reduction.

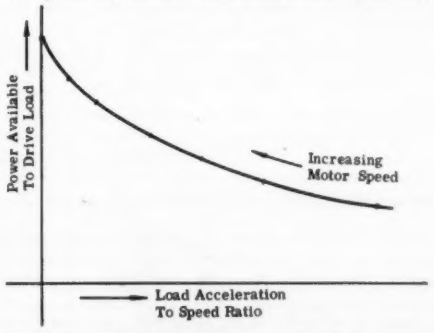


Fig. 9—Typical form of DLC. The marked points correspond to motor speeds. The ratio to the required load speed establishes the gear reduction.

The DLC may be determined graphically as described in the January-February issue of Electromechanical Design, pp 56-60, "Dynamic Load Characteristics of Electric Motors." Once established for a given motor, the DLC may be applied with no further effort to new problems. An assortment of DLC's for possible application to a given problem may be conveniently scanned to make an optimum selection.

Also, in the article "Generalized Dynamic Load Characteristic" starting on page 44 of this issue, Mr. C. H. Pearsall, Jr., of Fairchild Astronics Division presents an improved analytic method resulting in universal curves for immediate application to motors.

Fig. 10 shows the DLC for a specific unit whose performance and rotor inertia are known.

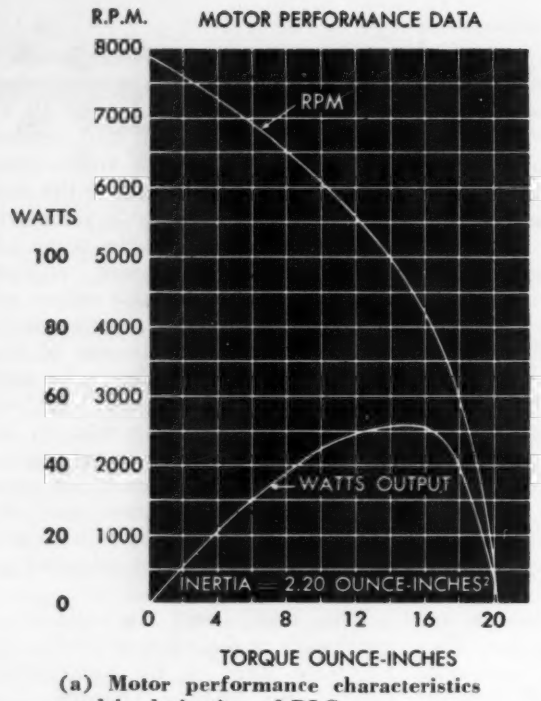
PRACTICAL APPLICATION FACTORS

The theory presented earlier in this Digest provides the necessary background for the analysis of motor application problems. In this section we will consider more practical factors affect-

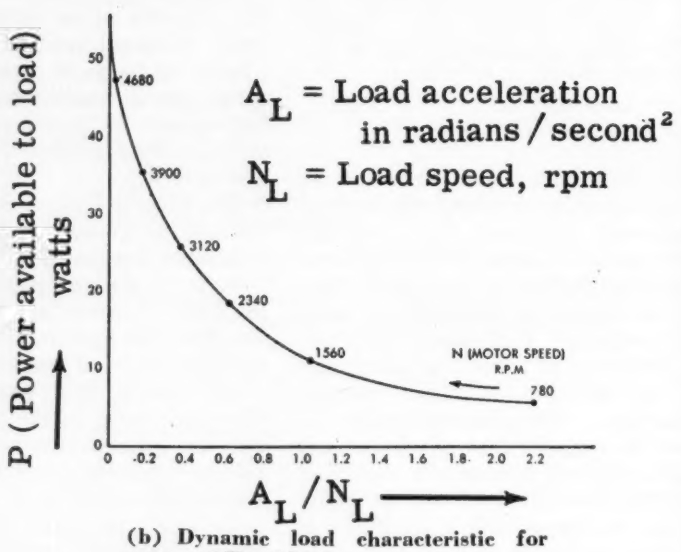
TABLE V
Some Standard NEMA Insulation Classes

NEMA Class	Max. Cont. Total Winding Temperature	Type Insulation
A	105C	Organic insulation and impregnation
B	130C	Inorganic insulation and organic impregnation
H	180C	Inorganic insulation and silicone impregnation

NOTE: The above classes of insulation are intended to provide tens of thousands of hours of life within their ratings. For military applications requiring 1000-2000 hours of life, insulation may be used perhaps 30C *beyond* the recommended limits. This extended limit must be utilized with care, however.



(a) Motor performance characteristics used in derivation of DLC.

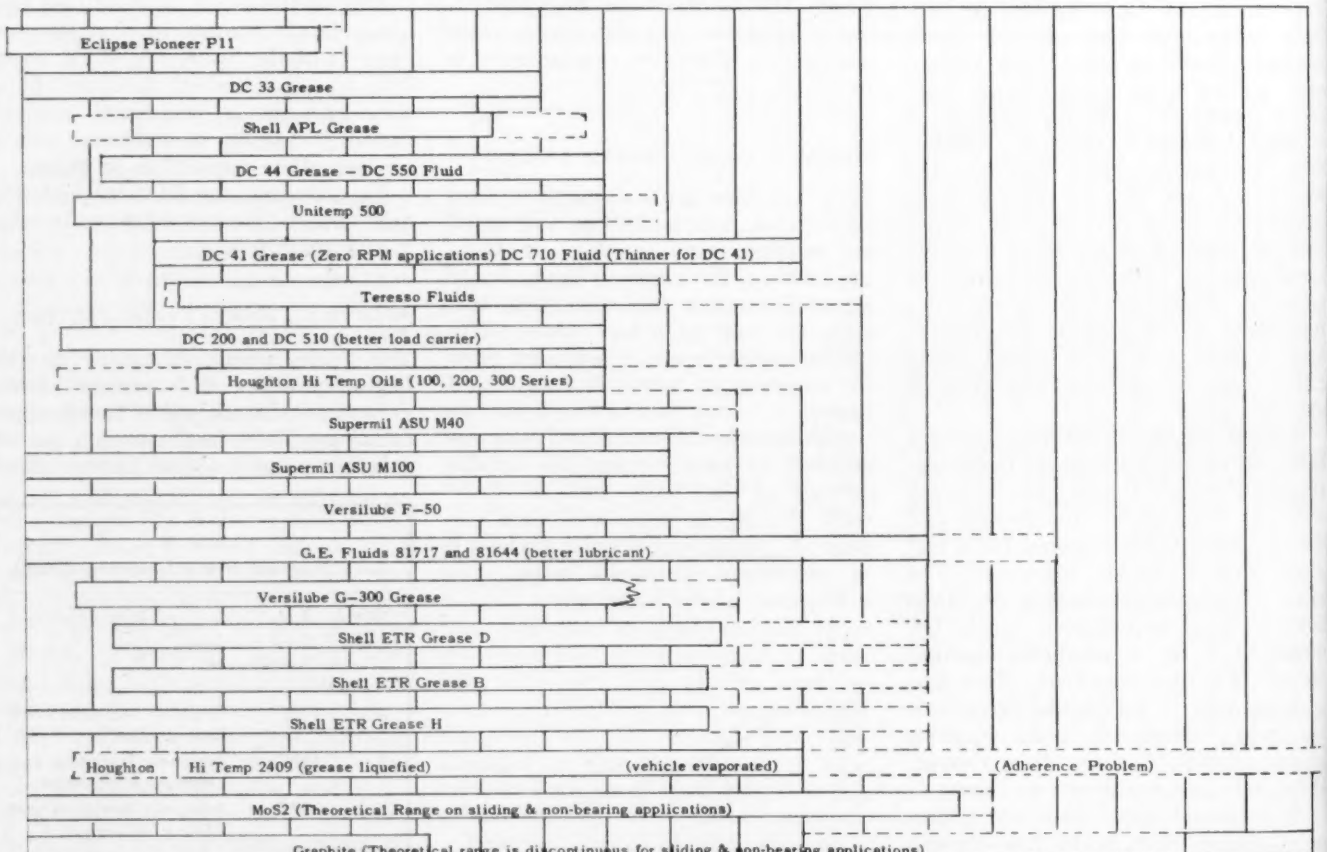


(b) Dynamic load characteristic for motor of Fig. 10(a).

Fig. 10—Fig. 10 (a) shows the speed-torque characteristic of a typical high slip motor. The DLC of the same motor is given in Fig. 10(b). Mixed units are used which are, however, consistent with current practice. Notice the inevitable loss of available motor power with increasing acceleration.

TABLE VI

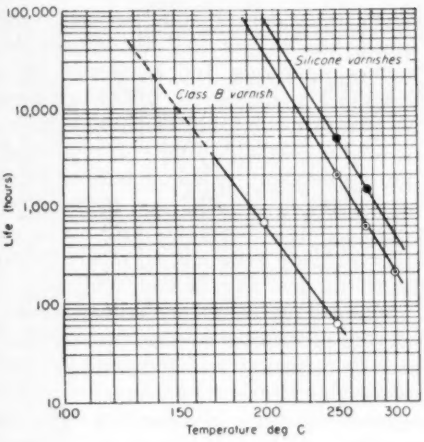
TEMPERATURE RANGE SELECTION CHART FOR OIL, GREASE AND DRY FILM LUBRICANTS


Eclipse Pioneer P11
DC 33 Grease
Shell APL Grease
DC 44 Grease – DC 550 Fluid
Unitemp 500
DC 41 Grease (Zero RPM applications) DC 710 Fluid (Thinner for DC 41)
Teresso Fluids
DC 200 and DC 510 (better load carrier)
Houghton Hi Temp Oils (100, 200, 300 Series)
Supermil ASU M40
Supermil ASU M100
Versilube F–50
G.E. Fluids 81717 and 81644 (better lubricant)
Versilube G–300 Grease
Shell ETR Grease D
Shell ETR Grease B
Shell ETR Grease H
Houghton
Hi Temp 2409 (grease liquefied)
(vehicle evaporated)
(Adherence Problem)
MoS2 (Theoretical Range on sliding & non-bearing applications)
Graphite (Theoretical range is discontinuous for sliding & non-bearing applications)
Silver & Gold Platings (incl. powders) (Theoretical Range on some sliding and non-bearing applications)
Lead Oxide (Decreasing coefficient of friction as temperature increases on non-sliding bearing applications)
–100 –50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900
TEMPERATURE (°F.)

Courtesy of N. H. Ball Bearing Co

Note: Dashed lines indicate extensions because of concessions in life or environment.

COMPONENTS DIGEST



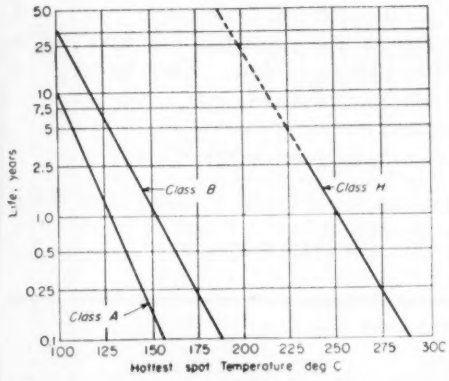
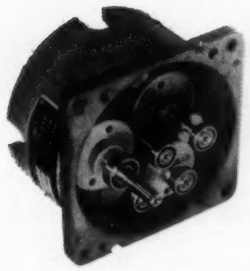


Fig. 11 (Top)—Thermal life of silicone insulating varnishes based on 50 percent retention of dielectric strength. (Bottom) Life at various temperatures for Class A, Class B and Class H insulation. (Dow-Corning Silicone Notes, No. 10-238, December, 1954).

ing the selection and use of a motor.

Since the biggest limitation to motor miniaturization is temperature rise, some of the effects of extreme temperature are worth considering. Insulation life decreases sharply with increased temperature, roughly halving for every 10 or 15 degrees centigrade increase (Fig. 11). This logarithmic relationship points up just how important it is to cut temperature rise, even by relatively few degrees. Table 5 shows the most common insulation classifications as listed by NEMA. High temperature insulation adds a lot to cost, particularly in large size units, so it is important to specify it with judgment.

Probably more of a limitation to motor life than insulation is bearing lubrication. Table 6 lists some of the common military specification lubricants and their important characteristics. A good bearing design must ensure that an adequate supply of lubricant is available to replace that which



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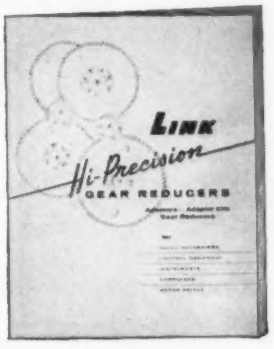

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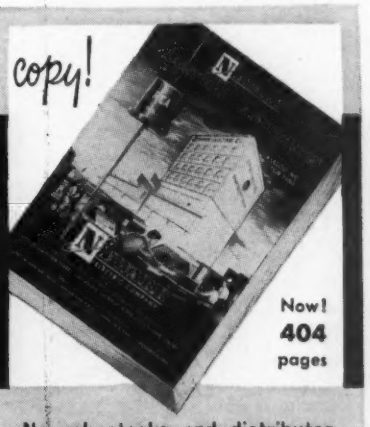

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SERIAL BINARY (LINEAR)	707 713 717 719	7 bits (128) 13 bits (8192) 17 bits (131,072) 19 bits (524,288)	128 128 128 128
SERIAL BINARY (SIN-COS)	757† 758†	7 bits per quadrant* (4 quadrants) 8 bits per quadrant* (4 quadrants)	512 1024
BINARY CODED DECIMAL (8-4-2-1)	723 724 733 734 735	2,000 20,000 3,600 36,000 360,000	200 200 200 200 200
GRAY	708	8 bits (256)	256

@All models available with internally mounted isolation diodes for sequential multiplexing applications.

†Available in hermetically sealed servo-driven package as Models 757-S and 758-S.

*Including limit 1 and polarity information. Sine and cosine functions generated simultaneously and independently. One turn of shaft generates 4 quadrants of information.

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is evaporated at high temperature. Protection from dust and air flow is also necessary to avoid dirt in the bearings, which is deadly, and oxidation of the lubricant caused by movement of air over its surface.

At low temperatures the lubricant must not stiffen so as to prevent the motor starting or reaching its specified speed.

Bearing fits are another factor materially affecting bearing life. Excessively tight fits at any temperature extreme can render the bearing inoperative within a short time. For this reason motors for operation over a wide temperature range generally use steel housings and caps rather than aluminum, to match coefficients of thermal expansion of the bearing to its seating surface.

Manufacturers offer temperature stabilized bearings for use at very high temperatures. The choice of material and its heat treatment are said to provide a maximum of dimensional stability. Special bearings intended for use with no lubricant for short periods are also being evaluated for temperatures above 500F-600F. Wide bearings with more lubricant capacity are sometimes recommended for moderately high temperatures. In general, the larger the bearing and the lower the speed, the longer the life. Currently, motors operating for hundreds to a thousand hours in a 200C ambient temperature represent the limit of commercially available units for production application. Ambient temperatures of −125C to +150C are much more common. Improvements in lubricants must precede advances in insulation to make the next step in improving life.

Thermo protectors are inherent overheating protective devices that respond to motor current and temperature and whose purpose is to protect the motor against excessive overheating due to overload, failure to start, or against smoke hazard. Automatic reset protectors are available in either single or triple heaters. The circuitry is shown in Fig. 12.

VARIABLE FREQUENCY MOTORS

In many instances a motor is required to operate over a range of frequencies, as contrasted with more conventional

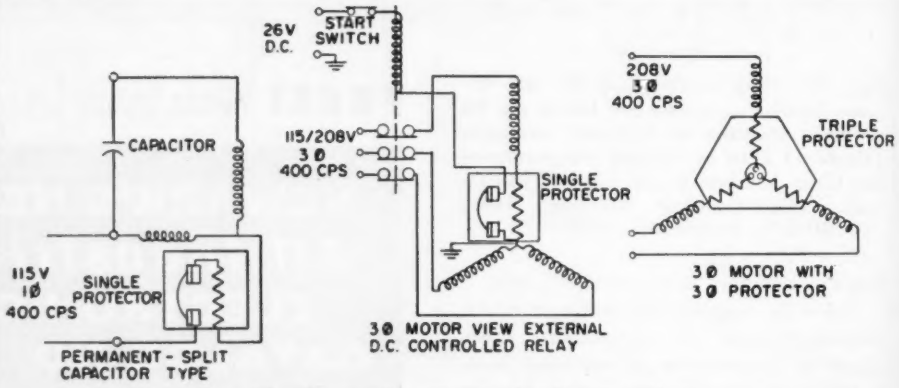

Fig. 12—Thermal protector circuit connections.

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0.5 MFD CAPACITOR — SINGLE PHASE

50 CFM at 0.25 INCHES OF WATER AT 7200 RPM

AMPS	WATTS INPUT	RPM
0.50	40	12000
0.45	35	10000
0.40	30	8000
0.35	25	6000
0.30	20	4000
0.25	15	2000
0	0	0

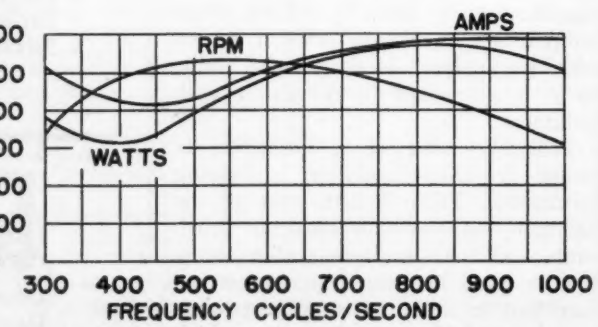

Fig. 13—Typical performance characteristics of a variable frequency blower unit.

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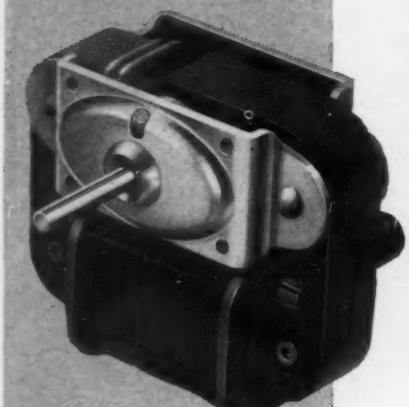

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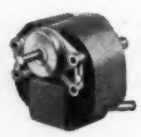

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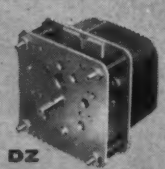

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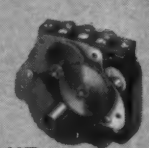

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single frequency (with a tolerance) operation. Typical ranges may cover 50 to 450 cycles, 300 to 2000 cycles, or operation in the vicinity of 60 and 400 cycles without circuit changes. This unorthodox operation is often required because of power supply characteristics, where aircraft engines, for example, drive a-c generators at speeds corresponding to engine speed, hence variable. Sometimes stocking of parts is simplified by using the same unit in both 60 and 400 cycle systems.

In any case, this variation in frequency must mean a deterioration in performance. A single frequency motor must be more efficient (at its rated frequency) than a motor designed to operate over a frequency range. Some of the factors affecting performance are apparent as discussed below.

Assume, as is most common, that a blower is to be driven at a minimum speed corresponding to a required air delivery (Fig. 13). Let f_1 and f_u correspond to the lower and upper frequencies of the range respectively. Since maximum theoretical speed of a polyphase induction motor under balanced conditions corresponds to its synchronous speed, $N_s = 120f/p$, where N_s = synchronous rpm, and f and p are respectively frequency (cps) and poles, the blower speed must be somewhat less than synchronous speed at f_1. This establishes the air delivery of the blower. With a properly adjusted unit, speed will generally increase in the intermediate band of frequencies, and finally decline at the high frequency end. In blower applications the fact that blower power varies as the cube of the speed tends to minimize speed excursions over the intermediate frequency band. At f_u, where speed declines to roughly the same value as at the low frequency point, a high slip condition occurs. That is, speed is low notwithstanding the high line frequency. From our previous consideration of equivalent circuits for balanced operation, the theoretical rotor power exceeds the shaft power by a factor of 1/(I-S), which can be very large at high slip. Due to unbalance in the individual phases which would naturally occur at most points in the frequency range, plus the occurrence of stator copper and core losses, the actual power requirements may be several times this figure. Thus, although only a relatively few watts of shaft power may be required, motor watts for wide frequency band operation may be quite high, an advantage of d-c machines.

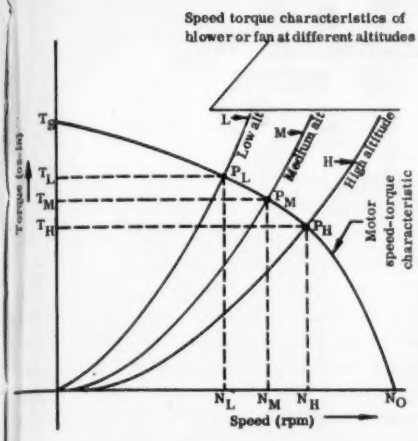

Fig. 14—Shift in operating point with altitude. The blower or fan speed-torque characteristic is parabolic The speed-torque characteristic of the motor indicates high slip, which produces a significant speed change with altitude. The higher speed at high altitude means more cfm of cooling air, which helps compensate for reduced air density and cooling capacity per cubic foot. In the diagram, T is the torque; T_S is the stall torque; N is the speed; N_O is the no-load speed; L, M, and H refer to low, medium, and high altitude respectively; P is the operating point of motor-blower combination at intersection of individual characteristics.

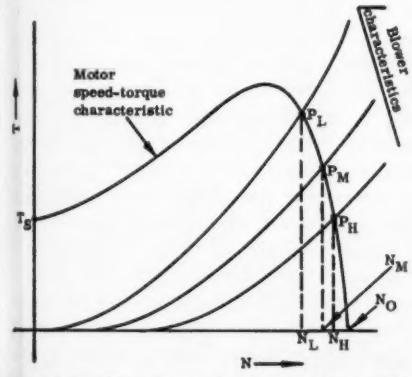

Fig. 15—Variation in operating point with altitude of a blower with a low slip drive-motor. Speed varies slightly with altitude. This makes for high operating efficiency in the vicinity of sea level, but a considerably reduced cooling capacity at high altitude.

MOTORS FOR BLOWER APPLICATION

Fan and blower drives are a very important application of small induction motors. The special requirements demanded in this application include combinations of the following:

- Absolute reliability. If the blower fails, excessive temperature rise may cause complete ruin of the equipment the blower was designed to cool.
- Operation at very high ambient temperatures, since blower use is basically associated with hot environments.
- High efficiency. Heat generated in the blower must be included with the total heat generated in the equipment.

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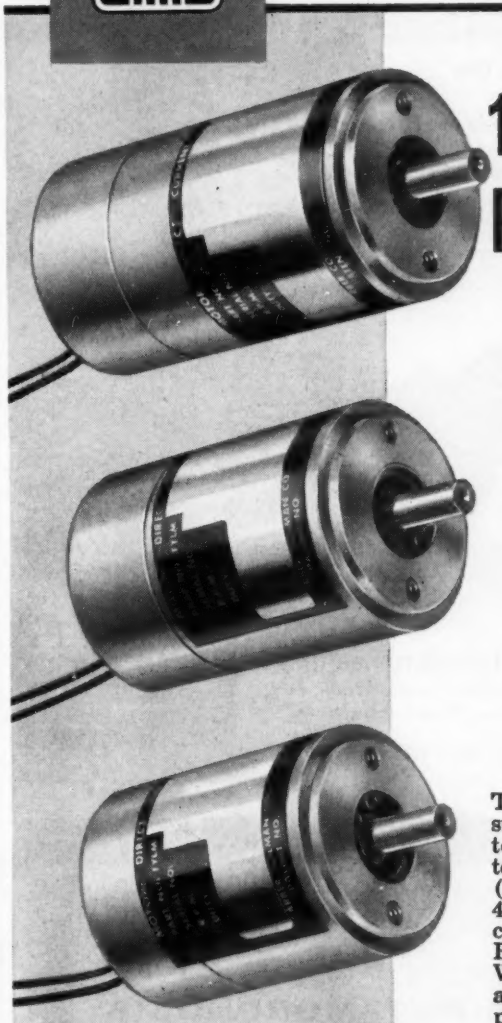
d-c small motors



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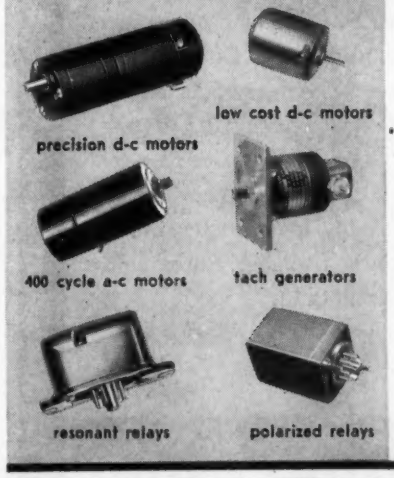
This popular sized motor can be supplied in voltages from 6V d-c to 115V d-c. Normal ambient temperature range −65° to 200°F (can be designed for −100°F or 400°F). Rated output, 10 mhp continuous to 35 mhp intermittent. Rated torque, .05 lb-in. to .16 lb-in. Weight, .26 lb to .43 lb. If you have a new or replacement motor application, contact Barber-Colman.



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#1 Pole 30 BBM contacts 75% duty cycle, data
#2 Pole 30 BBM contacts 75% duty cycle, data
#3 Pole 30 BBM contacts 50% duty cycle, sync pole

} Interpole phasing to within ± 20 minutes arc maximum. Sync pole leading edge electrically lags data pole.

MILITARY: MIL-E-5272A, MIL-I-6181B, IRIG

Temperature	−55°C to +85°C
Altitude	0 to 100,000 ft.
Vibration	15g 70-2,000 cps 3 major planes
Shock	50g 3 major planes
Acceleration	75g 3 major planes
Service Free Life	Minimum of 500 hours without service
Weight, 2,375 pounds	Full hermetic case.
Motor & Power	115 volts hysteresis synchronous 400 cycle less than 12 watts. 28 volt d.c. ungoverned less than 4 watts.
Contact Resistance	Less than 0.2 ohms total with a lifetime variation of approximately 0:03 ohms for the first 500 hours life.
Insulation Resistance	100 megohms at 500 V. d.c.
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COMPONENTS DIGEST

• Miniature size, since miniature equipment with tight packaging of heat generating components could not contain an oversize blower.

• Low starting torque. Since the torque required to drive a blower varies as the square of its speed, low-speed motor torque requirements are negligible in comparison with rated speed requirements. This gives the motor design some flexibility. However, torque must be adequate to insure starting in a reasonable time at cold temperatures where the bearing grease stiffens. The cold start picture is aided by self-heating in the stalled motor, which soon warms up the bearings, and the fact that cooling is not so critical at cold ambient temperatures. Notwithstanding these extenuating circumstances, cold start requirements are a necessary reliability factor.

• A safe temperature rise, even at altitudes above 50,000 feet where convection cooling becomes negligible, is a must in many blower applications.

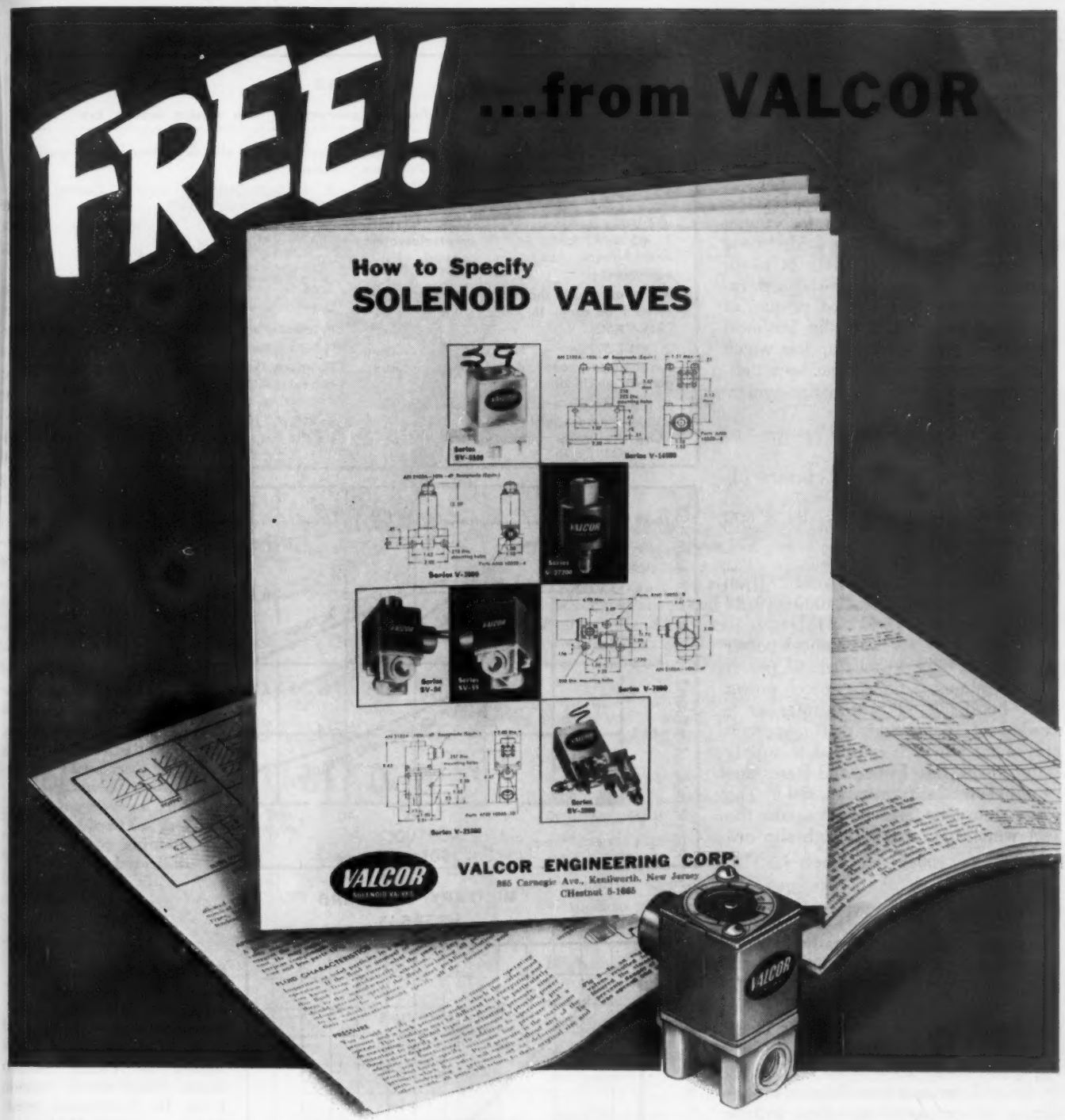
• For many applications where it is desired to provide a relatively constant supply of cooling air over a range of altitudes, the motor speed-torque characteristic must be chosen to provide a speed increase with decreased loading. Fig. 14 shows this type speed torque characteristic and its influence on the motor speed variation with altitude. For contrast, Fig. 15 shows performance with a low slip motor.

A low slip unit provides best efficiency at sea level. However, it provides almost no additional cooling at high altitude. To meet a cooling requirement at altitude with a low slip motor, it may be necessary to provide excessive low altitude cooling air. This often means a larger motor.

A high slip motor designed for altitude air-delivery requirements would lose speed at sea level. The number of poles becomes a matter of performance. High altitude speed approaches synchronous speed. Thus a 400 cps 2-pole motor may drive a fan at 21,000 rpm at 70,000 feet, and at about 5000 rpm at sea level. This means a 4/1 increase in cfm at high altitude where the air density is low. Fig. 16 shows the cooling characteristic of a Rotron "Altivar" fan as a function of altitude.

EFFICIENCY FACTORS OF HIGH-SLIP UNITS

Efficiency is diminished in high-slip units for these reasons: A high resis-



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CIRCLE 55 ON INQUIRY CARD

COMPONENTS DIGEST

tance rotor means more rotor copper loss at a given slip. The wide speed range results in mismatching of motor impedance to the phase-shifting capacitor except in a limited portion of the speed range. And, finally, but most important, there is rotor slip loss which is related to the shaft power by a definite function of slip. From the equivalent circuit data, Table 4,

Mechanical power=Rotor power × (1-slip)

Rotor power=Mechanical power/(1-slip)

For the example above, the slip at 500 rpm is

$$(N_s-5000)/N_s=\text{slip}$$

$$N_s=120f/p=120\times 400/2=24000 \text{ rpm}$$

$$(24000-5000)/24000=19/24$$

Rotor power=(1/[1-(19/24)]) × mechanical power

=(24/5) × mechanical power

Thus, almost 5 times as much power must be delivered to the rotor as is needed at the output shaft. Appreciably more power is required to supply stator losses, iron losses, and losses due to unbalance in the rotating field. The motor must be able to dissipate the heat which characterizes high slip operation.

ENVIRONMENTAL FACTORS

Electric motors are generally covered by the standard environmental specifications, such as MIL-E-5272A, MIL-STD-202, and MIL-E-5400. These specs have been outlined in our Components Digest 4, Environmental Testing (see March 1959 Issue of EMD). In general, environmental specs for ordering a new motor are best written around one of these standard specifications, with exceptions taken as indicated by the specific requirements of the application. Thus, the general statement can be made that MIL-E-5272A, paragraph "X" applies except as indicated; then list the exceptions.

Probably the most important exceptions have to do with temperature range, particularly in the high temperature region. Ambient temperatures of 150C are not uncommon. Difficulties arise in achieving a thousand or more hours of life under load at ambient temperatures such as this and higher. Continuous operation for the total life period at the highest ambient temperature is far more severe a requirement than the motor is likely to meet in practice where only a fraction of its life occurs at high temperature.

TABLE VII

The commonly used specifications encountered with electric motors are:

1. AF-32590—Motors; Aircraft, alternating current, 400 cycle, induction for: This spec is rather old, and although not official, it is actually superseded by MIL-M-7969A (ASG).
2. MS-33543(ASG) — Criteria-temperature and Altitude range, self cooled electric equipment.

All applications should be clarified as to curve I or curve II. This is part of MIL-M-7969A(ASG).

3. MIL-E-5272A — Environmental Testing Aeronautical and Associated Equipment, general specification for:
4. MIL-E-5400 — Electronic equipment-Airborne, general specification for:

There are many requirements that are not applicable to electric motors in this specification.

5. MIL-Q-5923B(USAF)—Quality Control of Aircraft and Associated Equipment.
6. MIL-E-7894A(ASG)—Electric Power, Aircraft, Characteristics of:

Type I power is 380 to 420 cycles.

Type III power is 150 to 1200 cycles.

Type II power is no longer listed.

Practically all the 400 cycle motors operate to type I power.

7. MIL-M-7969A(ASG) — Motor, alternating current, 400 cycle, 115/200 volt system, Aircraft, general specifications for:
8. MIL-M-17050(SHIPS) — Motors, Alternating-Current, Fractional HP (Shipboard use).

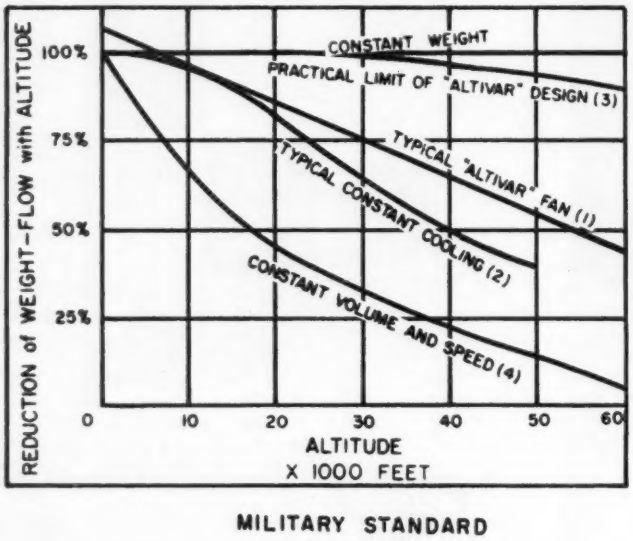


Fig. 16 — Characteristics relating to a Rotron "Altivar" unit. Curve (1) represents the weight reduction with altitude of air delivery from a typical "Altivar" fan. Curve (2) shows typical requirements for a constant cooling effect. The remaining curves are as indicated.

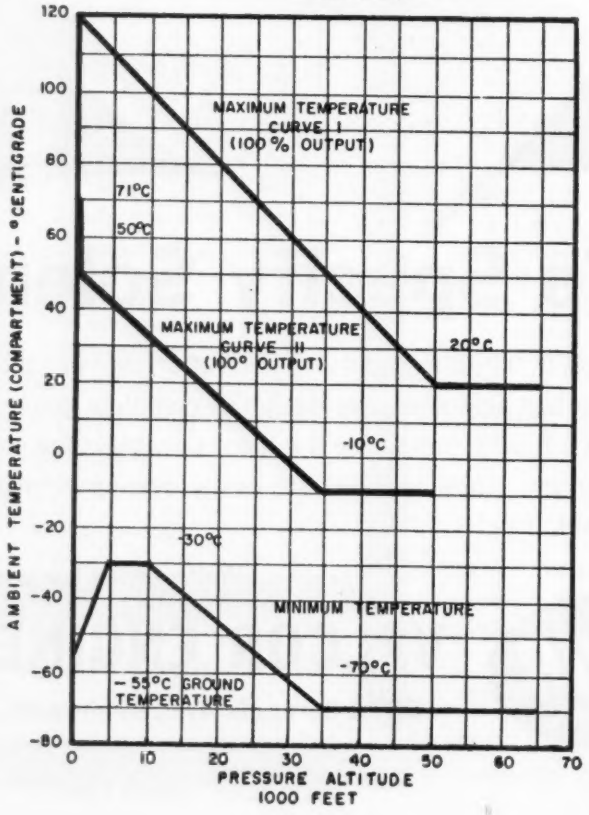
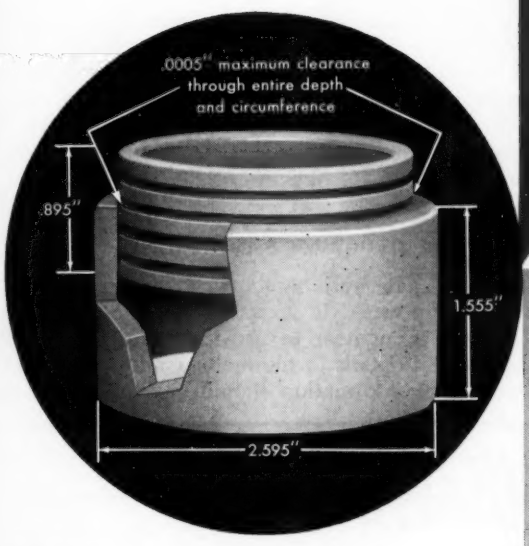


Fig. 17—Standard temperature vs. altitude characteristic. Minimum temperature curve is applicable to all equipment designed to either maximum temperature curve I or II. Maximum temperature curve II is applicable only for interim procurement and if specifically permitted by the detail specification or drawing. Test conditions per detail specification. Curve I indicates the maximum temperatures to which equipment must be designed to operate satisfactorily in unconditioned compartments of high performance aircraft powered by air consuming engines. Curve II indicates the maximum temperatures to which equipment must be designed to operate satisfactorily in conditioned compartments of high performance aircraft or in low performance aircraft.



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CIRCLE 56 ON INQUIRY CARD

COMPONENTS DIGEST

There are no generally accepted standards for life testing suitable for the types of motors we are considering. The application engineer frequently creates his own specification based upon estimates. A complete specification will cover the total required life, the time to be spent at each ambient temperature during the life cycling test, the speed of the motor and its load during the life test, the applied voltage and frequency (which normally have some tolerance), the duty cycle, reversing or non-reversing, and the mounting conditions.

Since life depends very sharply on the temperature within the motor, the matter of mounting becomes important. The temperature rise of small motors can be reduced to less than half by mounting on appropriate heat sinks.

Similar factors apply with respect to high altitude. Many motors are capable of delivering a rated output which is much more than would normally be expected for the frame size as a consequence of self-cooling. A fan assembly mounted directly on the motor provides good cooling, reducing temperature rise. Fan cooling becomes almost useless, however, at altitudes above about 50,000 feet and as a result, performance based upon self-cooling must be related to altitude conditions. High altitude may never occur simultaneously with maximum ambient temperature permitting an increased temperature rise (see Fig. 17) or the motor may be located in a pressurized area where cooling would be maintained.

Table 7 lists the commonly used military specifications applying to electric motors. Reference to these specifications provides a valuable background for the evaluation of motor applications. Note in particular MIL-M-7969A (ASG) which relates directly to the type of motor covered in this Digest.

ORDERING A MOTOR

Because motors are used in so many ways, it is safest for the application engineer to provide fullest application details to the motor manufacturer. This information should cover not only the

TABLE VIII • DATA SHEET FOR MOTORS AND GEAR MOTORS

Type of Motor: ☐ Open ☐ Enclosed ☐ Non-cooled ☐ Self-cooled
☐ Servo ☐ Synchronous ☐ Reluctance ☐ Hysteresis ☐ Salient
☐ Gear ☐ Induction

Nominal Voltages: _____V. Main Ø _____V. Cont. Ø _____V. 3 Ø line-to-line

Capacitor _____mfd. _____Volts _____H. P. Rating (s)

Frequency (s)

Phase Data:

Impedance Data (R + SX or Z at ∠): M. Phase C. Phase

Amperage: No Load:_____ Full Load:_____ At Stall:_____

Wattage: No Load:_____ Full Load:_____ At Stall:_____

Speed Rpm: No Load:_____ Full Load:_____ (If applicable, indicate 2nd speed & torque as a fraction.)

Torque (oz. in.) at_____RPM Min. Full Load_____Stall_____

☐ Motor Shaft Starting_____ P. I. Torque_____ P. O. Torque (for syn. motors)_____

☐ Gear Shaft

Temperature Rise (°C.)_____

Temperature Ambient (°C.) Low High

Duty Cycle: ☐ Intermittent Time On_____ Time Off_____ ☐ Continuous_____(How Long?)

Special Noise Requirements: Backlash

Rotation: ☐ Reversible ☐ Clockwise ☐ Counterclockwise (Viewed from lead end)

Connections: ☐ Terminals Type ☐ Leads No. Length " Type

Rotor: Moment of inertia in gm cm²

Max. Dimensions (except shaft): Dia. " Length "

Shaft Data: ☐ One End Dia._____ Ext._____ (Indicate flat, slot, etc., if applicable)
☐ Second End Dia._____ Ext._____ " " " " " "
☐ Splined Data:_____ ☐ Threaded Data:_____

Bearings: ☐ Sleeve ☐ Ball Class Type

Lubrication: ☐ Standard ☐ Special (Specify Type)

Life Expectancy:

Mounting: ☐ Flange ☐ Synchro Ring ☐ Other (Specify Type)

Weight: (Lbs. & Oz.)

Application: ☐ Commercial ☐ Military ☐ Applicable Specs._____

Nature of Application:

Other Requirements:

Use reverse side for color code, diagrams, and other comments.

Courtesy EAD

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COMPONENTS DIGEST

actual performance requirements, but as much background as possible on how the motor is to be used. These factors often profoundly influence design features.

Of particular importance is information on the removal of heat. There are no special standards on safe temperature rise for most applications, but only the requirement of adequate life. The motor manufacturer confines his temperature rise to what he considers a safe value compatible with the insulation and lubrication systems' limits. If a heavy heat sink is included in the final motor installation, the motor manufacturer should be so advised. It may make his problem (and yours) a great deal easier. Similar remarks apply to cooling air which may be available in the system package.

As discussed above, convection cooling diminishes at very high altitudes, and temperatures can become excessive. Specify altitude conditions. and the temperatures anticipated at these altitudes.

An often neglected factor in motor specifications is the definition of a satisfactory life. This is probably due to the difficulty in anticipating the nature of a typical life cycle, and a consequent natural tendency to leave the specification vague. A user of motors may, for example, indicate:
Operating temperature range –55C to 125C; Life 2000 hrs.
He is vague as to whether the specified life must be reliably obtained at +125C, a difficult specification to meet, or whether a room temperature life test is satisfactory. In the event of premature failures, he can protect himself by taking the former interpretation, although an initial strong stand here might have meant high prices, and long lead time for delivery of prototypes.

A more satisfactory approach would be to spell out a life cycle, for example:

500 hours at –55C
500 hours at +125C
100 hours at +25C (room temperature).

TABLE IX • DATA SHEET FOR FANS AND BLOWERS

	VOLUME		
TYPE	CFM (NAFM)	STATIC PRESSURE	CFM (NEMA)
Propeller Fan			
Tube Axial Fan			
Vane Axial Fan			
Centrifugal Blower			

Type of Enclosure: ☐ Open ☐ Enclosed ☐ Non-cooled ☐ Self-cooled

Voltage: Max. Amperage: Max. Wattage: H. P. Rating:

Number of Phases:

Frequency: Capacitor mfd. Volts

Speed:

Ambient Temp. Range (°C.): Low High

Duty Cycle: ☐ Intermittent Time On _____ Time Off _____ ☐ Continuous _____

Special Noise Requirements:

Rotation Centrifugal Blowers: ☐ Clockwise ☐ Counterclockwise — (Viewed from motor end)

Specify Discharge Location (3 o'clock position or other): _____

Rotation Propeller Fan: ☐ C.W. ☐ C.C.W. ☐ Air Over Motor ☐ Air Away From Motor

Rotation Tube Axial Fan: ☐ " ☐ " ☐ " " " ☐ " " " "

Rotation Vane Axial Fan: ☐ " ☐ " ☐ " " " ☐ " " " "

(Rotation determined looking from air discharge end.)

Max. Dimensions: Dia. " Length " Width " Height "

Connections: ☐ Terminals Type ☐ Leads No. Length " Type

Bearings: ☐ Sleeve ☐ Ball Class Type

Lubrication: ☐ Standard ☐ Special (Specify Type)

Life Expectancy:

Mounting: ☐ Base ☐ Outlet Flange ☐ Inlet Flange ☐ Strap Mounted ☐ Face Mounted ☐ Other _____ (Specify Type)

Weight: (Lbs. & Ozs.)

Application: ☐ Commercial ☐ Military ☐ Applicable Specs. _____

Nature of Application:

Other Requirements:

Enclosures:

Use reverse side for color code, diagrams, and other comments.

Courtesy EAD

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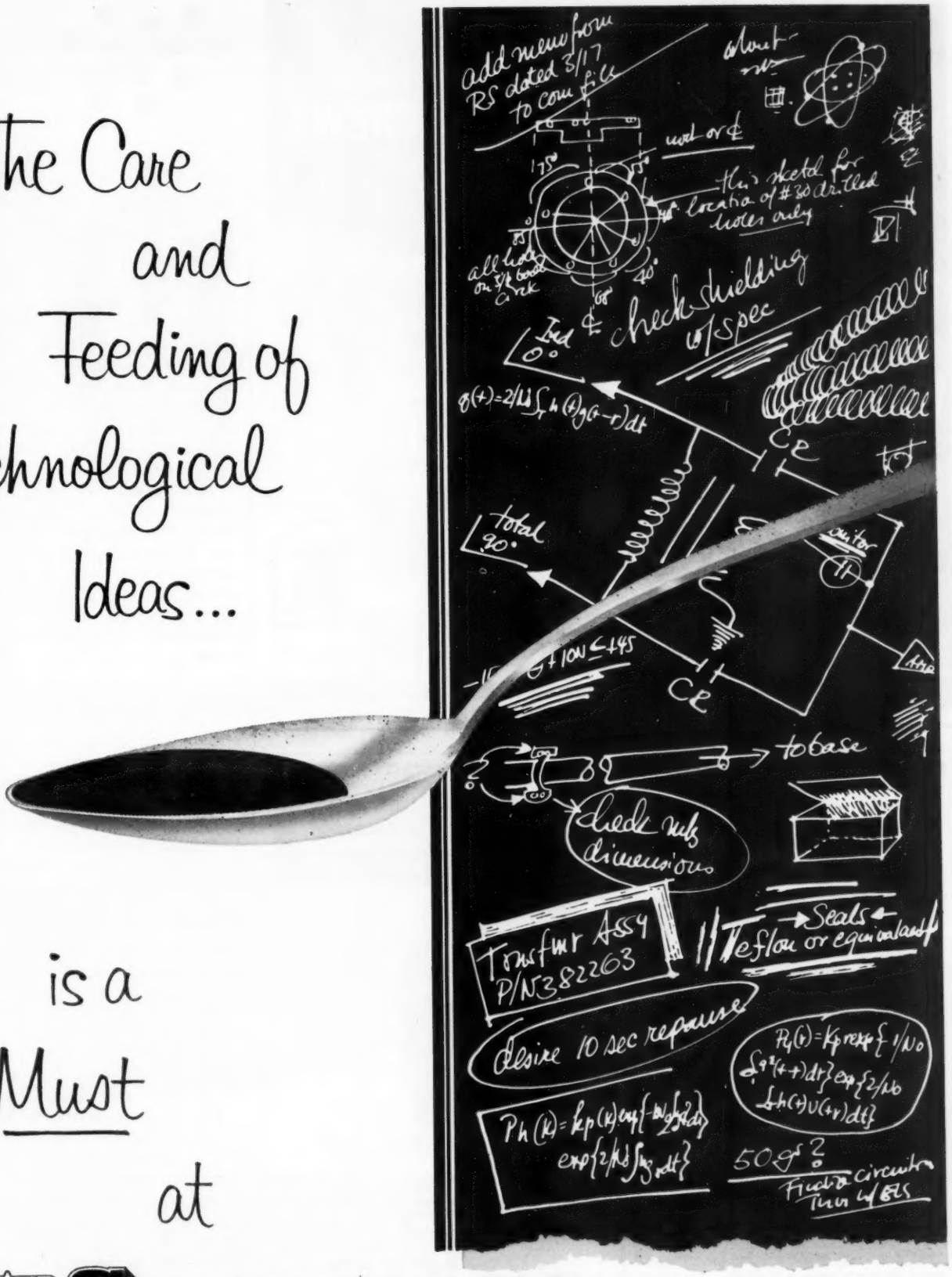
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all holes on 3/8 bolt circle
40°
Ind ℄ check shielding w/spec
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CE
total 90°
Monitor
Ant
CE
to base
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desire 10 sec response
Ph(k) = kp(k) exp{−½ ∫ g²(t) dt} exp{2/N₀ ∫ h(t) V(t) dt}
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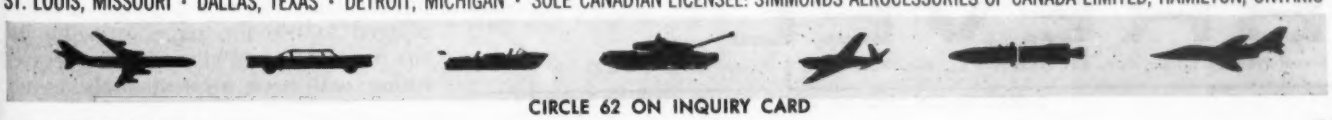

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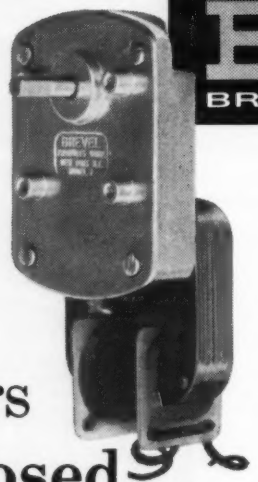

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CIRCLE 60 ON INQUIRY CARD

COMPONENTS DIGEST

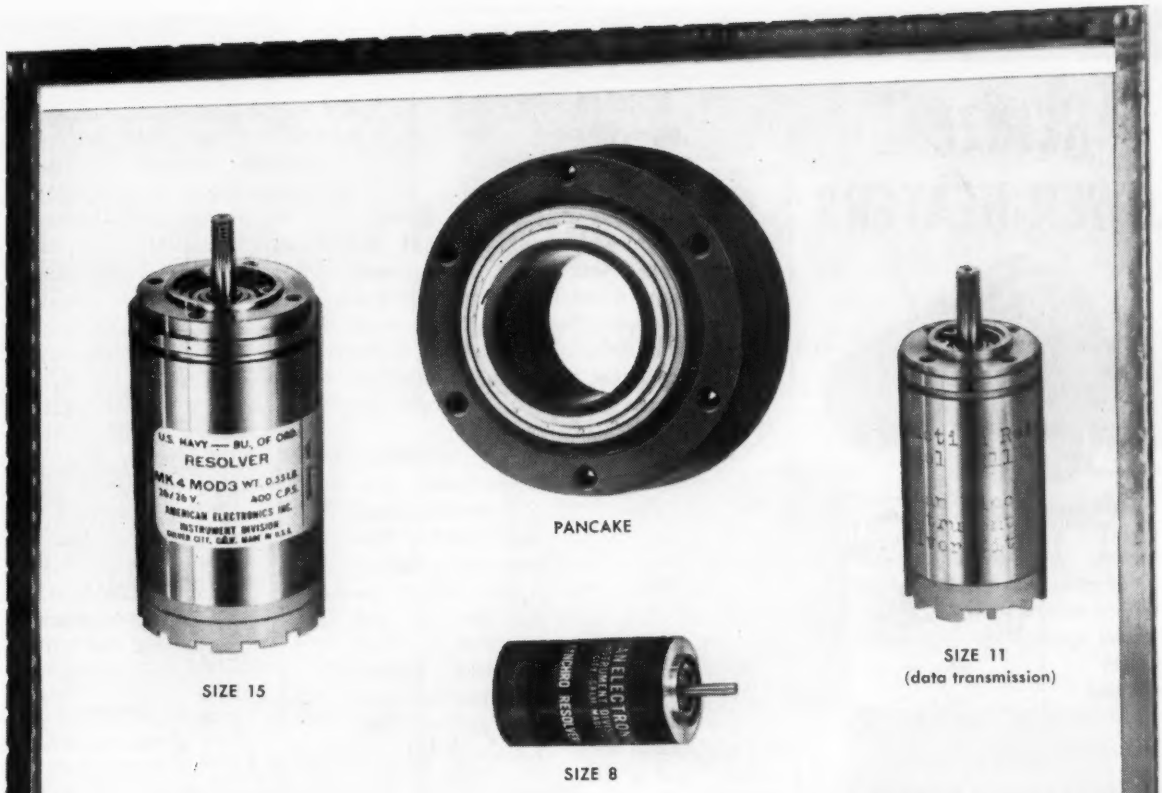
A further breakdown into shorter repeated cycles of specified duration at specific temperatures is also feasible. The method of mounting, position, and the manner of application of load must be specified. If load conditions are simulated by a brake on the motor shaft, then the flow of brake heat (motor output power) must be related to the actual operating condition. For a motor having 75% efficiency, three times as much heat will be developed in the brake load, as in the motor. This heat can be conducted through the shaft to the front bearing, resulting in premature failure.

Motor users are often vague about operation at other than nominal conditions. For example, where line voltage is given as 115 volts ±10%, and frequency from 380 to 420 cps, must *all* performance characteristics be met at the extreme tolerance conditions. Frequently, only nominal conditions are intended, but this is not always the case. Often, this point is not clearly stated.

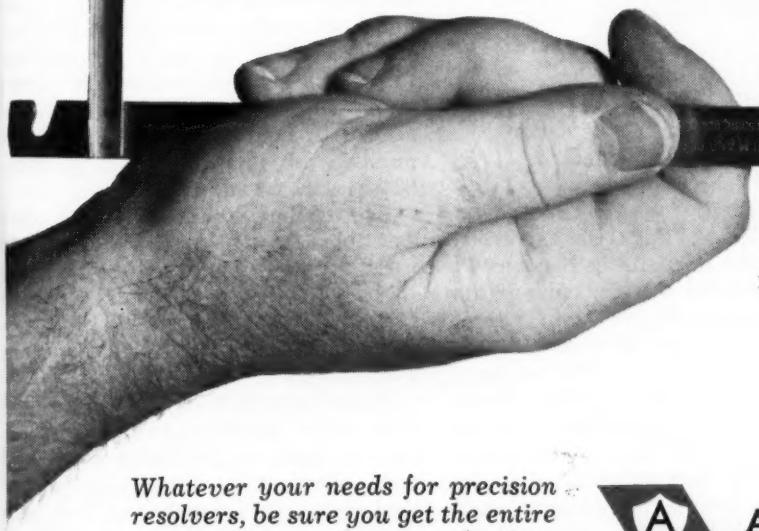
A low slip motor certainly changes speed with frequency. Power input varies as the square of line voltage at a given speed. High power occurs where frequency is low and voltage is high. Clarification is necessary.

Similar problems occur in blower applications. When blower performance has been specified, the temperature condition must be explicitly noted. Satisfactory room temperature porformance may occur simultaneously with much reduced speed and higher input watts at −55C where air density is greater. In actual use this probably introduces no problem, since cooling air is less important at low temperature, and motor wattage simply heats up the lubricant for easier rotation.

Electrical characteristics of the motor should not be specified in excessive detail, or redundancy. If power is available, the motor should be permitted to use it (within reason, and with attention paid to total heat within equipment). It is the manufacturers' responsibility to see that the motor meets life and reliability requirements. If only wattage is important, avoid specifying current and power factor. A particularly nasty problem is matching a motor to a given capacitor. This often occurs when it is desired to "second-source" a given capacitor motor. Here the new supplier is often obliged to use the same capacitor as the first source. While motors of equal rating will have approximately equal



THE COMPLETE RESOLVER PICTURE



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	Frequency (CPS)	Rated Input Voltage	Test Voltage	Input Impedance (Ohms)	Total Null Voltage (Max)	Max. Functional Error (%)	Transformation Ratio Rotor to Stator	Transformation Ratio Rotor to Compensator	Weight (Ounces)	Temperature Range (Degrees C)
IR8W4-602, SIZE 8 (Wind Comp.)	400	26	10	220 + j370**	10	0.1	.87 ± .020	.99 ± .020	1.8	−55° TO +100°
IR11N4-159, SIZE 11	400	57	11.8	356 + j1950	17	0.1	1.902 ± .038		4.7	−55° TO +125°
IR15W4-425C, Mk 4 Mod 3, SIZE 15	400	60	15	240 + j1000	15	0.1	.980 ± .020	1.000 ± .00025***	8	−55° TO +85°
25J90-44A, PANCAKE	1600	4	4	3600 + j5200	4	0.1	.975 ± .020	1.000 ± .002	6	−55° TO +85°
IR23W4-755*, Size 28	400	100	20	775 + j5650	16	0.03	.975 ± .020	.985 ± .010	28	−55° TO +85°

*Not illustrated. **Non/comp available with input impedances of 467 + j1580 Ohms and 130 + j370 Ohms. ***When trimmed with BuOrd Amplifier.

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CIRCLE 15 ON INQUIRY CARD

COMPONENTS DIGEST

volts - squared - × - capacitance figures, the capacitor value will depend directly on the power factor. Low power factor means a small high voltage capacitor. Mismatched capacitors can mean much reduced efficiency. Solution to capacitor matching difficulties requires an evaluation of economic as well as engineering factors.

Supplementing military specifications, many motor manufacturers provide standard form specifications sheets, suggesting in considerable detail the items to be considered in motor selection. The time spent filling in sheets of this type is especially rewarding in forcing the user to consider all the factors involved. Tables 8 and 9 provided by one manufacturer are particularly complete and are included here to serve as a check list.

EFFICIENCY

The principal direction of current developments is toward increased output in a given frame size. This is accomplished by use of improved materials lately becoming available, careful electrical design, and the judicious use of cooling. Consider the following fundamental relations —

$$\text{Efficiency } (\eta) = \frac{\text{Power out } (P_o)}{\text{Power in } (P_{in})}$$

$$\text{Losses } (P_L) = (P_o) - (P_{in})$$

By manipulating these relations, (P_{in}) may be eliminated,

$$(P_o) = (P_L)\ (\eta/1-\eta)$$

Since temperature rise is proportional to losses, this last expression represents the relationship between P_o and efficiency for a given temperature rise (assuming negligible iron saturation, which is usually the case in higher frequency components). This relationship is plotted in Fig. 18, which shows the sharp increases in output in a given frame size as efficiency is increased. P_L is approximately proportional to the temperature rise, ΔT. If T_a represents the maximum ambient temperature, and T_{max}, the maximum permissible temperature within the motor, then

$T_a + \Delta T = T_{max}$, and

$\Delta T = k\ P_L$, where k is a proportionality factor depending upon motor size and cooling.

Then, solving,

$P_L = (T_{max} - T_a)/k$ which may be substituted in the above equation relating output and efficiency.

$$P_o = (T_{max} - T_a)/k(\eta/1-\eta)$$

This last relationship shows that motor output depends not only on its

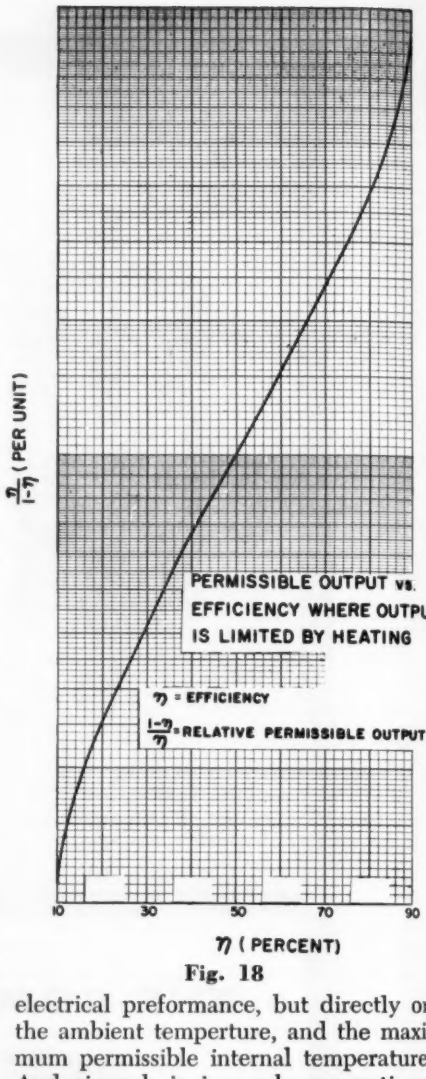

Fig. 18

electrical preformance, but directly on the ambient temperture, and the maximum permissible internal temperature. And since k is inversely proportional to the efficiency of cooling, the power output may be increased in many instances by factors of 2 or 3 by incorporation of improved cooling techniques such as an internal fan.

Fan cooling, while generally very desirable, presents special problems in variable speed motors where cooling is sharply cut at low speeds (where it is probably most needed) and subtracts appreciable mechanical power at high speeds.

Maximum output is usually derived from high speed motors. High frequency units are becoming more and more prevalent in missile applications. High frequency generators deliver high output on a given frame size. These units operating in the vicinity of 1000-2000 cycles are increasing in importance. On the other hand bearing life is sharply reduced, particularly when high-speed and high temperature are encountered simultaneously. Gear reduction units also present more of a design problem at high speeds.

On the other side of the picture, 400 cycle motors are often required in redesigned equipment to substitute for 60 cycle motors. Here a typical specification may require a motor speed of

3000-4000 rpm, requiring 12 or more poles. So many poles means low efficiency in the smaller frame sizes. As a matter of fact, depending upon the slot combination, the large number of poles may not even be feasible.

Pump and oil well applications call for motors to operate totally submerged in fluid. Although the fluid may present significant drop, cutting down available output, it is an excellent means of cooling, substantially lowering temperature rise, or increasing permissible output. If the fluid serves as a good bearing lubricant, the bearing life problem is markedly alleviated. Resin encapsulation of the windings is generally required. Compatibility between exposed surfaces and fluid must be checked.

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Source: Cincinnati Sub-Zero Products,
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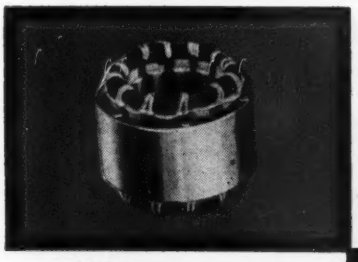

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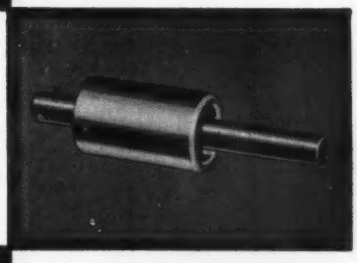

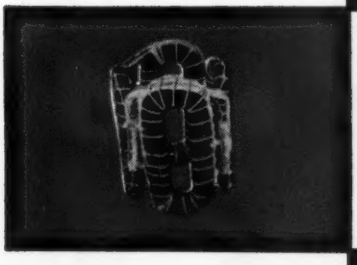

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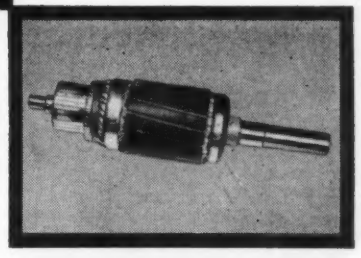

Celco does not manufacture complete motors. Our engineering and production know-how is devoted to the specialized manufacture of precision motor components, particularly for the aircraft, missile, and high quality commercial motor, synchro and generator producers. "Celco" is equipped to tool and fabricate stators, rotors and armatures completely or wind customer supplied stator, rotor or armature cores. Reduce your cost. Take advantage of our low pricing and timely deliveries.

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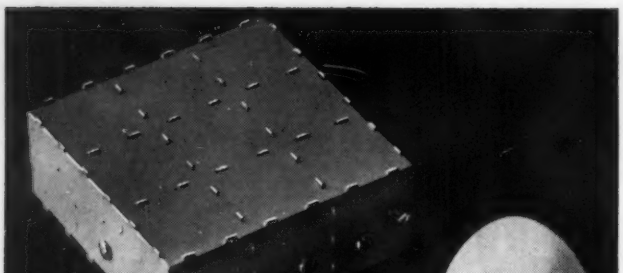

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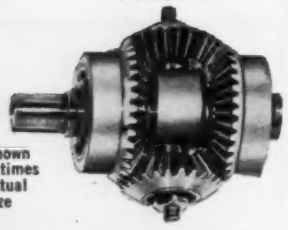

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